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Metals and Alloys

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WHEREVER LIGHT WEIGHT, STRENGTH

CONSTRUCTION EQUIPMENT

This 10-cu. yd. capacity heavy-duty Hug Truck assembled in Los Angeles by SIX WHEELS, Inc., is used almost exclusively in highway building and similar work that requires special construction to withstand punishing service. U·S·S COR-TEN used in the body plates and in the double channel frames (the outer of 5/16" COR-TEN) insures extra strength, of ¼" COR-TEN, the inner corrosion resistance and high resistance to wear and abrasion that will keep this equipment on the job.

TRANSPORTATION

COR-TEN, used in body framing and all stress-bearing members, makes it possible to reduce weight 2600 lb., increase capacity 200 cu. ft. in this fleet of 10 Bekins semi-trailers built by the Utility Trailer Manufacturing Company, Los Angeles. Says the builder, "We have more than 300 COR-TEN Steel bodies now in highly successful operation. Its tremendous strength and elasticity greatly increase resistance to 'metal fatigue' and insure long life and uninterrupted service."

BEKINS

VAN & STORAGE CO.

NATION-WIDE MOVING

MARINE

U·S·S COR-TEN was applied to the entire flat bottom of this tow boat. It reduces excessive wear of stern hull plates adjacent to the paddle wheel where severe erosive action occurs when the wheel stirs up sand, gravel, ice, etc. when the boat is reversed. COR-TEN's 33 1/3% greater resistance to abrasion, high corrosion resistance and high tensile strength make it far superior to wrought iron or ship steel for such hull construction.

Metals and Alloys in Home Washing Machines

by HERBERT CHASE

This article is another in a series on Metallurgical Needs of the Non-Metallurgical Industries—industries which depend largely on metals and their alloys for essential parts. The various metals which go into the building of a modern household washing machine are discussed by an author who has written many articles in the trade and technical press.

A list of previous articles which have been published in this series will be found at the end of the article.—The Editors.

WASHING MACHINES FOR HOME USE fall into a category different from other types of equipment treated heretofore in this series of articles, because such machines are necessarily designed for and produced in large quantities. To realize such sales volume, it is essential that costs be kept as low as feasible while insuring acceptable performance in service.

Materials and Cost

Since materials are an important factor affecting cost, construction must be largely confined to materials near the low end of the cost scale. Minor elements, and a few parts which provide certain special qualities, may be made from alloys costing somewhat more.

But, because the commoner materials are low in cost, their utility to industry is increased and as much care is exercised in their selection as in choosing the less common and rather specialized materials for particular purposes. It may even be more useful to the average reader of METALS AND ALLOYS to outline the reasons surrounding the selection of the commoner, low-cost materials than to confine the series largely to types of products somewhat out of the ordinary and requiring rather special materials for their construction.

For this reason, a fairly typical washing machine produced by the General Electric Co., and known as their "Model AW-311," is here chosen for consideration. Its basic elements include a tub in which washing is accomplished through the means of an agitator which is given a slow oscillating motion about a vertical axis; a frame with legs for supporting the tub; a wringer for removing water from fabrics washed; and the necessary motor and mechanism for actuating the agitator and wringer. When required, there is added a small pump for discharging wash water from the tub to a sink or drain at a higher level than the tub bottom.

Except for the rubber hose and rubber covered wringer rolls, and a few dielectric parts and gaskets, practically the entire assembly is made from metals or metal alloys. Thanks to the low cost of sheet steel and to the ease of fabricating sheet steel parts by stamping and drawing operations, this material and these methods of production are employed for many parts. Many parts are cast, however, and several others are fabricated from wrought steel which is purchased in rods or tubes.

Since appearance is an important factor affecting sales, and the cost of applying a finish is considerable, it is necessary that nearly all external parts—and some internal ones—be as smooth as it is practical to make them without machining or polishing or paying a premium for other extra operations prior to applying the finish. Naturally, some machining is required where good mechanical fits are necessary, but even this is minimized by the choice of materials and by making the most of production processes which yield smooth surfaces and dimensional accuracy without extra operations.

The Steel Tub

Since economy as well as good design dictate the use of a one-piece steel tub, it is necessary that this be made from deep drawing stock. Similarly, since the desired serviceability and appearance dictate a vitreous enamel finish on both inside and outside of the tub, it is essential to use a material which will take and hold this finish. The material chosen is a highly ductile low-carbon sheet steel known as deep drawing vitreous enamel stock. The tub is

purchased ready for use from specialists in deep drawing and enameling work.

Most of the remaining drawn and stamped parts are fabricated from hot-rolled, low-carbon steel sheet or strip which has been pickled to remove scale and then oiled to prevent rusting while the material is in stock. The cover is drawn from this material and is then zinc plated, after which the exterior surface is given an enamel finish of synthetic resin type, which is baked on. The skirt, legs and braces, making up the frame which supports the tub, are stamped and drawn or formed by rolling to required shape, after which they are Granodized to provide a rust resistant surface and a good base for the baked

General Electric home washing machine. Most of the important stamped and drawn parts, including cover, tub, skirt and legs are seen in this view.

synthetic enamel finish which is subsequently applied. Practically no machining is done on the stamped parts and, as the sheet is smooth, no grinding or polishing is required before applying the finish.

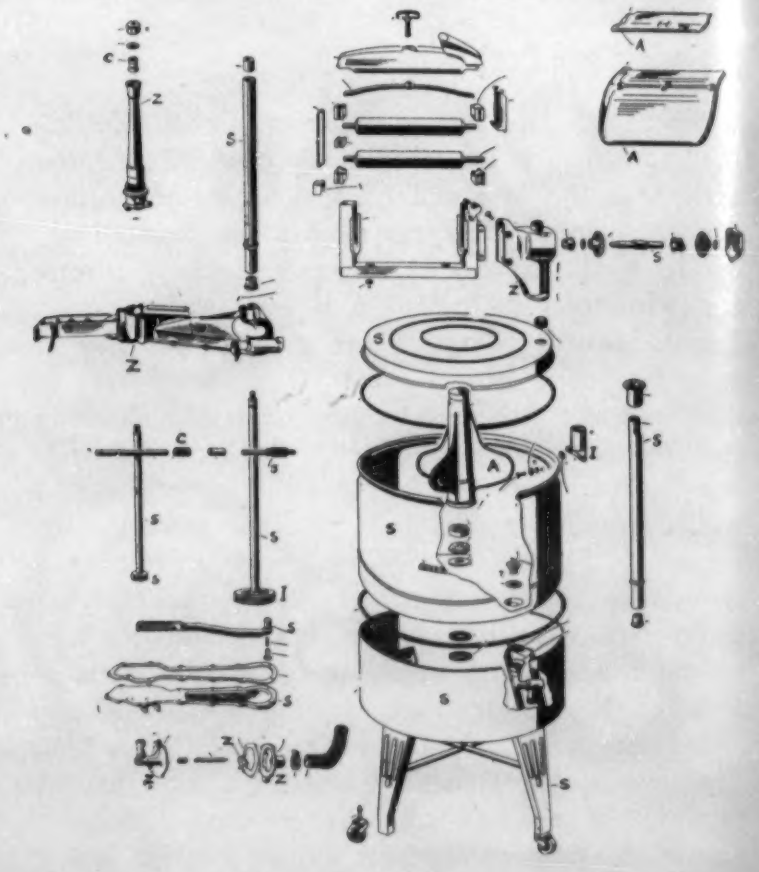
Other parts produced from wrought steel include the tubular post which acts as the wringer support and the motor driven shaft, both of which are made from hot rolled steel tubes having electrically welded seams; the agitator shaft and wringer drive shaft, which are made from cold-drawn screw stock equivalent to S.A.E. 1112, low in cost and having a smooth surface. The rack, which meshes with a pinion on the lower end of the agitator shaft, is made from forging stock similar to S.A.E. 1035. A worm is machined from S.A.E. X 1315 steel, chosen because it is readily machinable, of adequate strength and easily hardened.

Castings

Nearly all remaining parts are castings, but only one of these, namely, the bracket, which supports the wringer post and attaches it to the tub, is a gray iron casting. This bracket is a simple part which requires very little machining and is made with a surface which, though exposed, is not prominent and is smooth enough so that no grinding is required. The only other ferrous casting is a high test cast iron worm gear, selected because it is low in cost, yet affords the required degree of wear resistance. Considerable machining, including the cutting of the gear teeth, is required on this casting.

Aluminum alloys are used for two castings. One of them is a drain board, which is die cast; the

"Exploded" view of the washing machine, showing most of the major and some of the minor parts, the character of material employed being indicated in most instances by the following letters: A, aluminum alloy; C, copper alloy; I, iron casting; S, steel in wrought forms; and Z, zinc alloy die castings, the latter including the gear case, parts for the wringer and its drive and parts for the pump.



other is the agitator which is produced in a permanent mold. The composition and more important physical properties of these alloys are given in Table I. Aluminum alloys are used in these applications because they show a minimum of discoloration when subjected to the strong washing solutions sometimes used. The castings also are smooth and moderate in cost, require very little machining (except to remove flash, an operation performed by the suppliers) and are light in weight. The latter is an advantage in reducing inertia forces on an oscillating part, such as the agitator, though this is a minor factor when the motion is as slow as in this application.

Table I—Composition and Properties of Aluminum Alloy Castings

Composition:	Permanent Mold Castings Per Cent	Die Castings Per Cent
Copper	6.0-8.0	2.0-2.25
Silicon	1-3	11.0-13.0
Aluminum	balance	balance
Magnesium	0.05 max.	0.10 max.
Manganese	0.3 max.	0.30 max.
Iron	1.5 max.	2.0 max.
Zinc	2.2 max.	0.75 max.
Tin	.....	0.10 max.
Nickel	.....	0.50 max.
Others, total	1.0 max.	0.20 max.
Properties:		
Tensile strength, lbs. per sq. in.	24,000	33,000
Elongation in 2 in., per cent	0.5 min.	1.0
Charpy impact strength, ¼ x ¼-in. test bar	.....	2 ft.-lb.

Parts produced in aluminum alloy, that in the center being the permanent mold agitator. Those at the right and left are alternative types of drain boards which are die cast.

Die Castings

By far the largest number of castings are those produced in dies from zinc alloy to A.S.T.M. No. XXIII (S.A.E. No. 903) specifications. These are made to the composition given in the Table II and have the properties there given, but the properties are not a part of the specification. There are many of these castings and they range in size from a gear case, which measures over all about 27 x 8 x 4½ in. and weighs about 11½ lbs. to wringer parts weighing a few ounces or less. The primary reason for using zinc alloy die castings is that they afford lowest over-all cost, but other reasons include the smooth surface realized (important especially for exposed parts), minimum machining required, and freedom from red rust. Naturally, use is predicated on satisfactory physical properties which include a much higher impact strength than gray iron castings. Smooth surfaces are important in lowering finishing

Table II—Composition and Properties of Zinc Alloy Die Castings (A.S.T.M. No. XXIII; S.A.E. No. 903)

Composition:	Per Cent
Aluminum	3.5 to 4.3
Copper, max.	0.10
Magnesium	0.03 to 0.08
Iron, max.	0.10
Lead, max.	0.004
Cadmium, max.	0.005
Tin, max.	0.005
Zinc of 99.99+ per cent purity	Remainder
Properties (averages realized but not named in standard specifications)	
Charpy impact strength ¼ x ¼-in. test bar	20 ft.-lb.
Tensile strength, lbs. per sq. in.	40,300
Elongation in 2 in., per cent	4.7
Compressive strength, lbs. per sq. in.	60,500
Brinell hardness	74

costs on exposed parts including some which are electroplated.

Initially, in designing this washing machine a gear case sand cast in gray iron was contemplated and put in use on some machines, but high cost for machining and the need for using a separate bracket for supporting the motor (which is now carried in a pair of simple stampings used as inserts in making the die cast case) led to a redesign and the substitution of the die cast case which has been used with success for many years. Recently, the die casting itself was redesigned with substantial reduction in its cost, but without any sacrifice in stiffness or utility. Other elements die cast in zinc alloy include many parts of the wringer assembly, the center post (located inside the agitator), drain fitting and pump parts, and several portions of the wringer drive and drive housing.

Bearings

Bearings are among the few parts of the washing machine in which alloys of copper are employed and some of these are of porous graphite bronze which, for bearings of moderate size, is low in cost and facilitates lubrication. It has been found that this form of bearing at the upper end of the center post (which guides the agitator shaft and is at a point where some heat and steam may be present) prevents squeaks and gives satisfactory service. The lower bearing for this shaft is in the gear case, which is filled with a heavy oil providing plenty of lubrication, hence a bearing directly in the die casting is found satisfactory. For the worm shaft, one bearing, which is also well lubricated, is also in the zinc alloy case, but the other bearing for this shaft, that facing the motor, is of porous bronze, as this has proved less likely to result in oil leakage.

Facts concerning some of the minor parts of the washing machine assembly might be given, but those considered of special interest to readers of this publication have already been mentioned. That the choices outlined above were wisely made becomes apparent in the light of experience over many years during which many thousands of machines basically the same as that here described have been giving an excellent account of themselves in service. This has been accomplished in the face of plenty of competition only through costs being held within required limits through the use of materials and production methods which are economical, yet which do not sacrifice performance characteristics of the machine in its completed form.

Related Articles in Metals and Alloys

"Special Metals in Oil Field Practice." P. H. Brace. Vol. 5, Sept., 1934, page 181.

"Metals and Alloys in Dentistry." O. E. Harder. Vol. 5, Nov., 1934, page 236.

"Metals and Alloys in the Pulp and Paper Industry." J. D. Miller. Vol. 5, Dec., 1934, page 263.

"Some Metallurgical Aspects of the Radio Tube Industry." Stanton Umbreit. Vol. 6, Oct., 1935, page 273.

"Metallurgical Needs of the Glass Industry." R. D. Smith. Vol. 7, Sept., 1936, page 217; Oct., page 263.

"Metals and Alloys in the Printing Industry." B. W. Gonser and S. Epstein. Vol. 8, Jan., 1937, page 3; Feb., page 59; Mar., page 63; April, page 117.

"Metals and Alloys Used in Diesel Locomotive Cabs." Edwin F. Cone. Vol. 8, Oct., 1937, page 271.

"Metals and Alloys in Aerial Cameras." Edwin F. Cone. Vol. 10, Feb., 1939, page 33.

"Metals and Alloys Used in Making Rubber Tires." Edwin F. Cone. Vol. 10, July, 1939, page 198.

A Chuckle

Light Pulverized!

To the Editor: In your columns you are continually poking fun at us "non-professionals" for blaming all otherwise unexplainable failures of steel on "crystallization." There may be a lot to these scientific subjects that you big shots don't know. By way of illustration, permit me to refer you to the all-time high in super-scientific accomplishments. The item which follows, taken from the program of the annual convention of Certified Boiler and Elevator Inspectors Association, held in Los Angeles, will no doubt merit the attention of your staff as a real scientific "scoop."

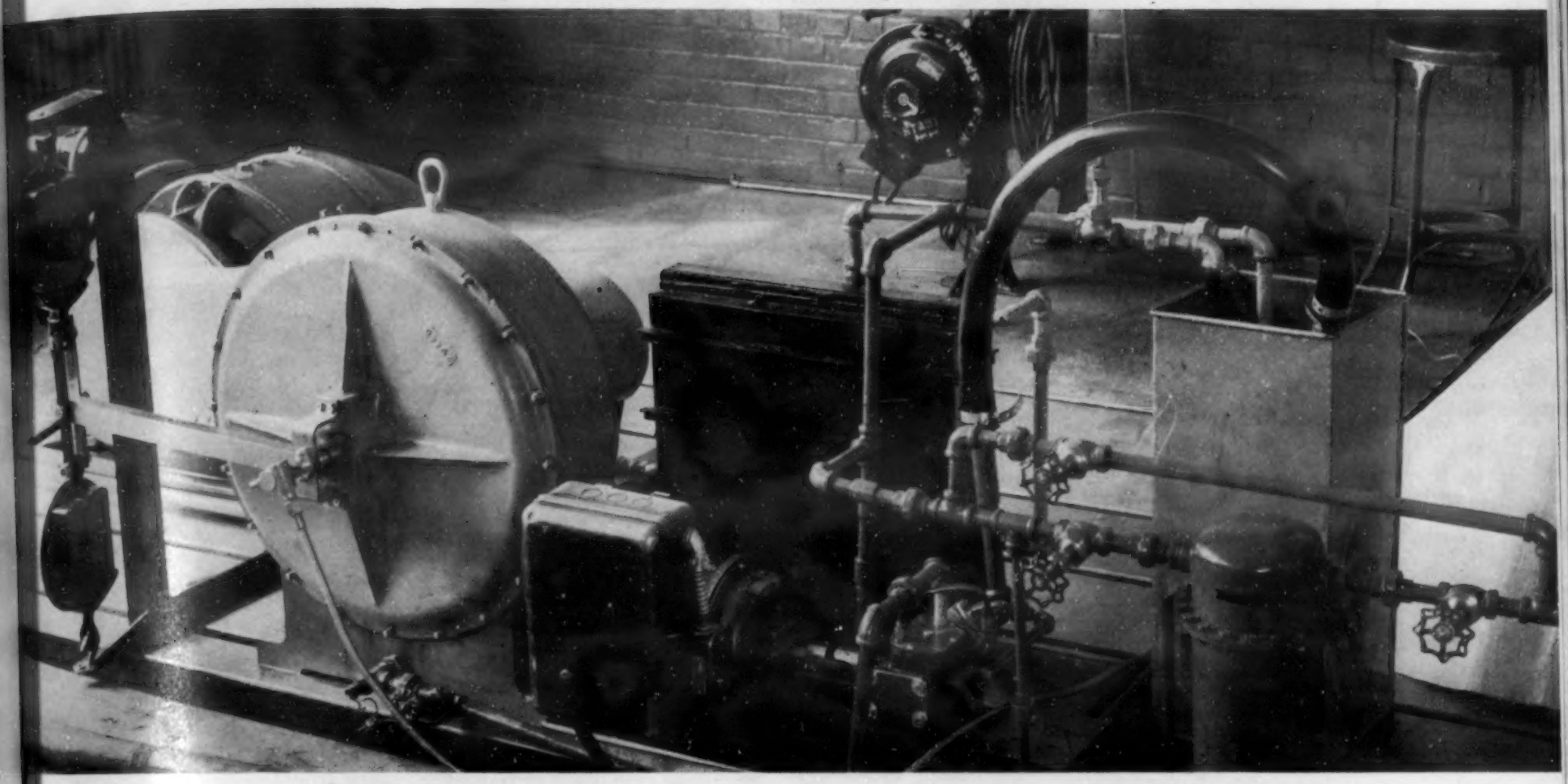
"Study and Observation of Stress Distribution which Pulverizes Light"—by A. P. Maradudin, Standard Oil Co.

By way of explanation, Mr. Maradudin has given a number of talks, illustrated with models, on the "Study and Observation of Stress Distribution with Polarized Light." He was asked to present this subject before the convention and he gave the title verbally to the program arranger with the above humorous result. Thousands of copies were publicly distributed.

ANONYMOUS

A Machine for Testing Bearings

Fig. 1. The Pratt & Whitney bearing test machine.



by EARLE A. RYDER

Consulting Engineer, Pratt & Whitney Aircraft Division, United Aircraft Corp., East Hartford, Conn.

In the evaluation of bearing metals, the mechanical properties that would count in a structural member are of relatively little importance, it is the actual behavior as a bearing that must be found out. Some factors of bearing behavior can be moderately well sized up by small scale tests, but, after the obviously unfit materials have been eliminated by such tests, the promising ones have to be studied as bearings, and in just the type of service for which the bearing is planned.

Hence the testing problem is, how to reproduce the exact conditions of service in the most inexpensive and convenient fashion.

For radial aircraft engine service, Mr. Ryder has produced a useful solution. The most important lesson to be gained from this example is that each gradation of bearing service will demand its own specific solution.—H. W. G.

IN THE DEVELOPMENT of aircraft engines for higher and higher output, the load capacity of the crankpin bearing, also called the master rod bearing, has been one of the limiting points. The load carried on this bearing is in the neighborhood of 3500 lbs. per sq. in. at take-off horsepower, and about 5500 lbs. per sq. in. in a dive. Full-scale testing on complete engines consumes a great deal of time and is also very expensive. It is necessary to assemble the engine with the test bearing, put it in the test house, run it on whatever routine has been decided upon and then put the engine back in the shop, tearing it down completely in order to inspect the bearing which has been tested.

In the course of engine development, Pratt & Whitney Aircraft has done much full-scale bearing testing on actual engines. In addition to this work, dummy engines have been utilized, each one consisting of the power section of a standard engine, motored over by an electric dynamometer instead of being run under its own power. Bearing tests run under these conditions are not quite so valid as those in full-scale engines operating under their own

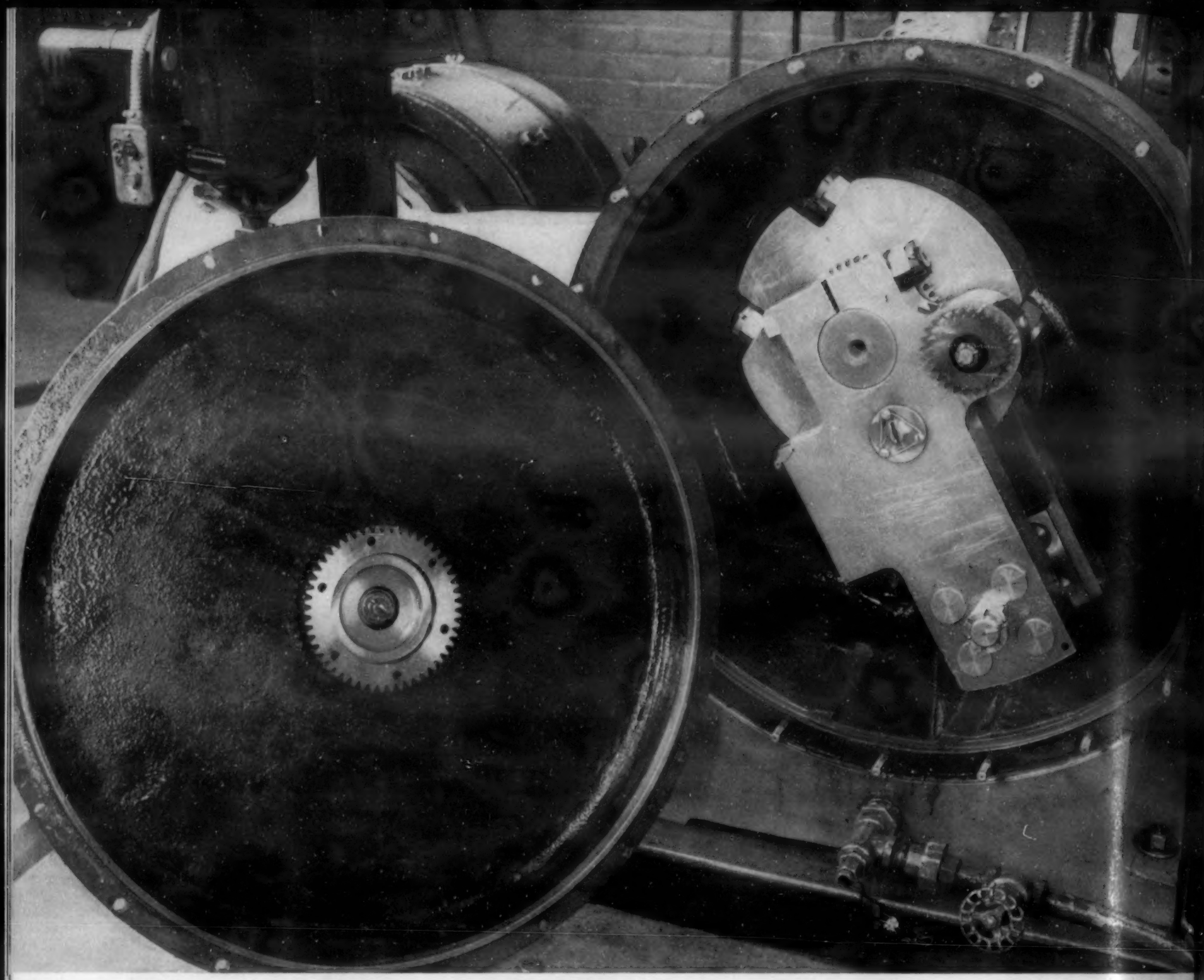


Fig. 2. Bearing tester with cover removed.

power. However, much useful information has been gained at a considerable saving in time. While the above methods were adequate for getting results, they required tying up a dynamometer and were a little cumbersome for some purposes. It was thought that a preliminary test should be developed for trials of new materials, something at least good enough to weed out the very bad materials, and if possible give results good enough to replace some of the full-scale testing in engines or dummies.

Designing the Test Machine

In designing a bearing test machine, the following features were considered important:

1. The machine should accommodate full-size bearings and test them up to and beyond the present limits of engine speed and load.
2. It should be possible to look at the test bearing easily and replace it in the machine without disturbing it. Assembly and disassembly should be as easy as possible.
3. The test journal should be replaceable.
4. The test machine should contain no heavily loaded bearings except the test bearing.
5. The machine should be completely balanced so that high speeds could be accomplished.
6. Provision should be made for indicating the friction torque of the bearing.
7. It should be possible to use the apparatus for testing either oil or bearings.

Such a machine was built and has been in use for more than a year. When first set up, it did not give familiar answers on materials with which we had lots of experience in complete engines. Some of the difficulties encountered will be mentioned below. After making some mechanical changes, and with sufficient experience in its use, this machine now gives reliable results and is a valuable addition to the engine laboratory equipment.

The general set-up is illustrated in Fig. 1. The

round housing at the left of the bed plate is the bearing test rig, driven by a variable speed motor shown in the background. The torque arm extending to the left of the cover registers the friction torque on a spring scale. The other apparatus seen in the picture is for heating, filtering, and pumping the oil supply to the test bearing.

Description of Machine

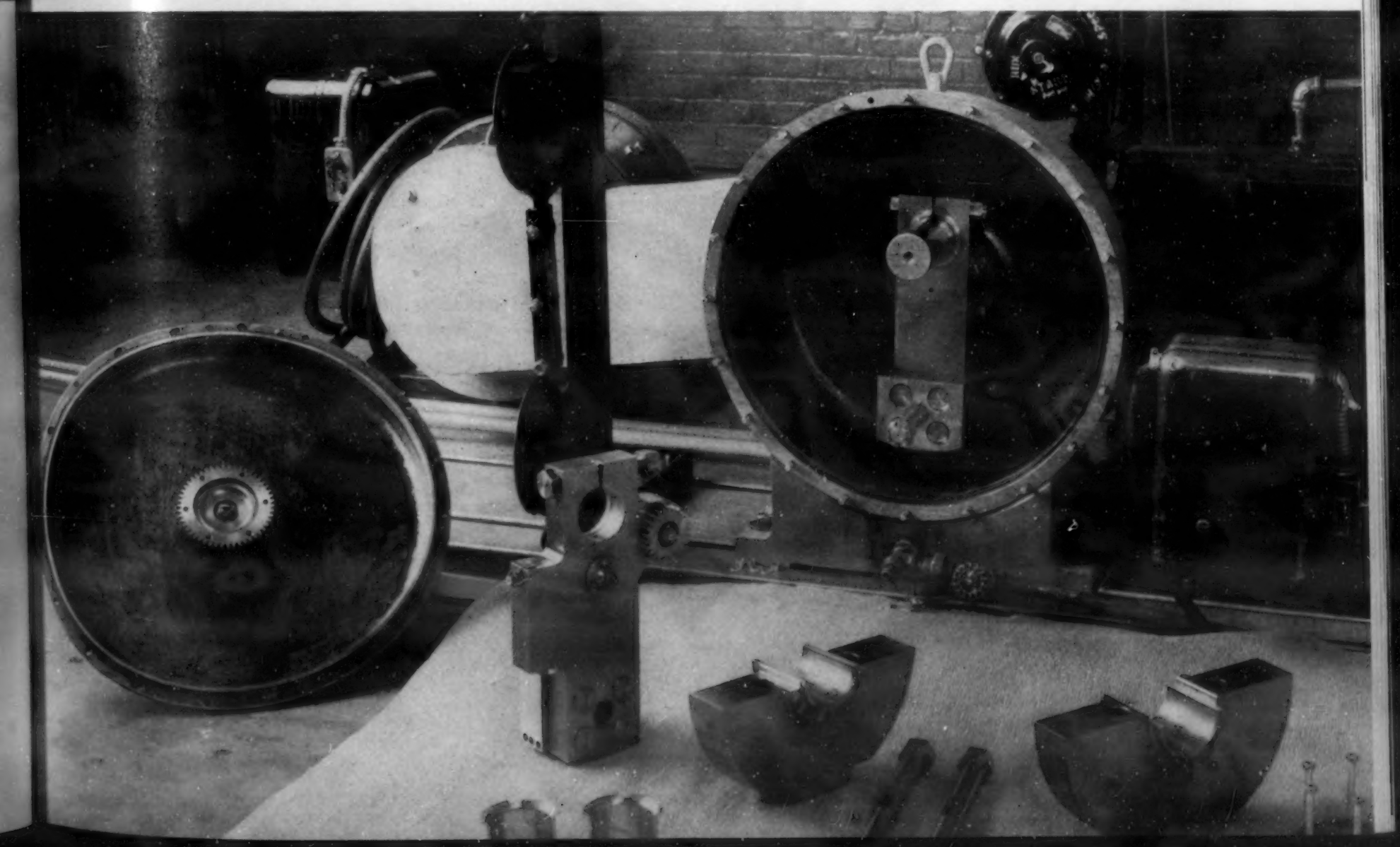
In a radial engine the load on the crankpin varies approximately as the square of the speed, since it is largely due to the centrifugal effect of the connecting rod cluster. The crankpin load is not very much affected by throttle opening, but is somewhat less at full throttle than it is at closed throttle for the same rotative speed. The load travels around the bearing, instead of being a reversing load, such as occurs on a crankpin serving a single cylinder.

To simulate the above conditions the test bearing is assembled into a split weight which is carried on a crankpin, but kept from rotating with the pin by a train of gears. Fig. 2 shows this arrangement. The front end of the crankshaft is supported in the cast iron housing of the test machine by two ball bearings and driven by "V" belts from a variable speed motor. The crankshaft itself is made in three parts, the front part including one cheek and the front centerline extension. The rear cheek is a second piece and the crankpin is clamped in both cheeks. The counterweights butt against each other and are secured by a large bolt which is seen in the picture. The bearing support is made in two halves held together by large bolts and in the machine shown weighs about 50 lbs., which is the order of the master balance weight of the Pratt & Whitney 1830-B engine. Since the stroke of the crankshaft is also approximately the same as that of the engine, the bearing load for any given speed practically duplicates engine conditions. Other weights can be used, of course, to procure other conditions.

Attached to the weight is a spur gear which meshes with a pinion mounted in the crank arm. This in turn is attached to a similar pinion on the rear face of the crank arm which meshes with a stationary gear mounted in the rear cover. This latter gear has a bearing in the cover and is attached to the torque arm by a clamp joint. The clamp has a bronze bushing and can be set previous to a test so that slippage will occur at a predetermined torque. If the bearing then seizes while it is being tested, or if the friction goes up above the predetermined value, the test bearing turns round with the crankpin and slippage occurs at the torque arm. This allows the machine to be stopped before destroying the bearing. A torque arm clutch setting of 500 inch-pounds has been found suitable for the size bearing tested in the machine shown,—namely, 2⅝ dia. x 3¾ long, and with this setting when a bearing seizes, it may be slightly scuffed and the crankpin may be blued. The bearing surface will not be completely torn up, and it is possible to see in what part of the bearing seizure took place.

The torque arm scales indicate the bearing fric-

Fig. 3. Bearing tester disassembled.



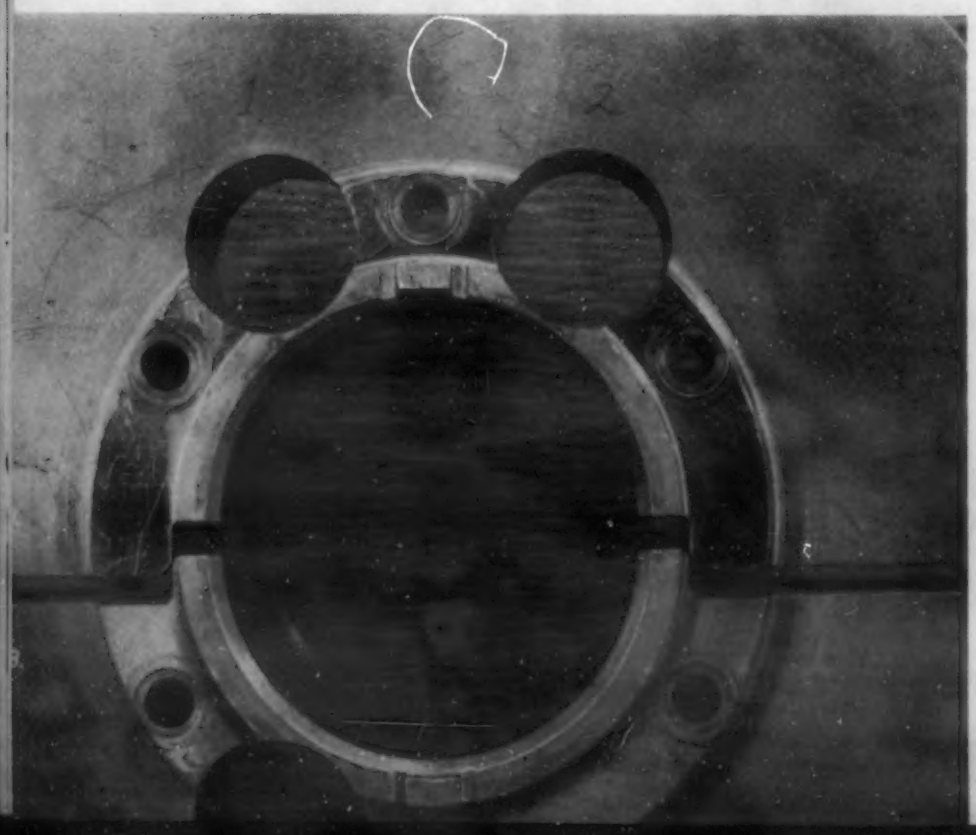
tion plus that of the pinions and pinion bearings. This latter increment, however, is relatively small and the indicated torque is sufficiently near the actual bearing friction to be useful for any comparative work.

The crankpin is removable from both crank arms and can be replaced as often as necessary. In the machine shown, the crankpins are made of SAE 2512 steel, case hardened on the outside. They are drilled with oil holes in the same location as used in the engine crankshaft. The journal surface has the same ground and lapped finish as used on an engine crankshaft. The same crankpin can often be used for several tests. However, if the test is run to the point of bearing failure, it is likely that the crankpin will be burned and should be thrown away.

Oil is fed in under pressure through a gland on the driving end of the crankshaft and the tachometer drive is taken off through the center of the torque arm attachment at the opposite end of the machine. An improvement which is not shown in the pictures is the addition of a pilot bearing between the rear crank cheek and the torque arm gear to insure alignment of this gear with the crankshaft axis.

Fig. 3 shows some of the parts disassembled. The test bearing is shown in the left foreground and in the case illustrated is a split bearing. One piece bearings can be tested equally well. To examine a bearing during or after a test, the rear cover is removed and then the rear crank arm clamp bolt is removed and the counterweight bolt nut taken off. This allows the rear crank arm to be withdrawn. After this the round weight containing the bearing can be lifted off the crankpin without disturbing the bearing in any way. The bearing can be examined while it is in the weight and if desired can be replaced in the machine for further running. It is not necessary to use as many studs as are shown in the housing to hold the cover on. Four or six nuts are sufficient. The whole operation of opening up the rig, examining the bearing and replacing it can be done in a relatively short time.

Fig. 4. Rotating weight, showing weakening holes.



Several of the round weights should be provided, all balanced alike, so that while one bearing is being tested others can be fitted in the shop. The relation of speed and load on the test bearing is shown in Fig. 5. Using the weights illustrated, the bearing load is 7700 lbs. per sq. in. at a speed of 4000 r.p.m. This is about the highest speed that can be obtained with the 15 h.p. D.C. motor, shown in the pictures.

Method of Testing

For any useful results it is necessary to have a well-built machine which is accurate in every part, and to have the test bearings fitted just as carefully as though they were going to be incorporated in a complete engine.

In using the Pratt & Whitney machine, it has been found necessary to thoroughly warm up all parts of the machine before running any tests. The method of doing this is to heat the oil and pump it through the bearing and also through two large squirts which enter the sides of the case and throw oil on the outside of the round weight. By circulating hot oil for half an hour or so before starting up the rig, the housing and weight, which are quite heavy parts, will be brought up approximately to the oil temperature, so that no expansion troubles will result when the bearing is run. With the hard bearing metals which are now customary for airplane engines, there is no advantage in a long run-in because the bearing surface does not change. Different kinds of bearing tests may be done, among which may be mentioned:

a. Dive testing to max. speed and load.
b. Sticking test with scanty lubrication.
c. Fatigue.

The Dive Test

So-called dive testing is intended to simulate engine conditions in a dive with closed throttle. With some kinds of bearings, limiting engine speed is determined by what the bearing will stand under this condition. The routine used for dive testing has been to run 1½ hrs. at 1500 r.p.m., then increase the speed to 2000 r.p.m. on the course of a half hour and after that run 1 hr. at 2000 r.p.m. After that the dive test is started and the speed is increased 50 r.p.m. every two minutes until the bearing fails, that is, until slippage occurs at the torque arm joint. The oil used is the same oil that is used in the engine test houses, and has a viscosity of 100 seconds Saybolt at 210 deg. F. The oil is fed into the crankshaft at 160 deg. F. A separate scavenge pump removes the oil from the bottom of the housing and returns it to the tank. Oil pressure at the input to the crankshaft is 100 lbs. per sq. in.

Frequent checks are made on types of bearings on which considerable engine experience has been had,

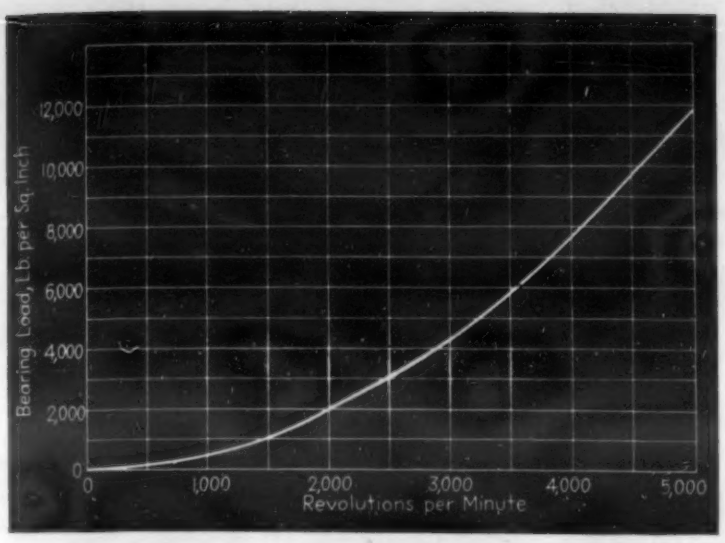


Fig. 5. Load speed relation in test bearing.

for instance, PWA-121 bronze which is 70 copper, 30 lead, and PWA-224 bronze which is 25 lead, 3 tin, balance copper. A typical test of the PWA-224 material is test No. 120 in which the bearing was run on the above routine and seizure took place at 3250 r.p.m. (See Fig. 6). The crankpin used was one which had been used on two previous tests where seizure did not occur. It was in good condition at the start of this test. After the bearing failure at 3250 r.p.m., the crankpin was blued in a streak about 5/8 in. wide on the underside; that is, toward the center of rotation of the shaft. The bearing was scuffed all the way around in a band about 5/8 in. wide near one end. The seized area of the bearing showed lead color. This bearing material has seized in dive tests of a complete engine in the range of 3000 to 3300 r.p.m. and in numerous tests on the bench machine seizure has occurred in the same speed range.

PWA-121 is a non-seizing material and has been run repeatedly to 3800 or 4000 r.p.m.

The Sticking Test

Another type of test that has been very useful in the development of bearing metals consists of running in the bearing at a moderate speed and then, with all conditions stabilized, cutting off or reducing the oil supply to the crankpin. The object of the test is to see how long the bearing will then run with only splash lubrication from the case. Numerous tests of this kind have been conducted in the dummy engine previously described. The PWA-224 bearing material seizes quite reliably in 90 to 120 seconds after cutting off the crankpin oil supply. The 121 material will run indefinitely on the oil which is splashed into it from the crankcase. In running this kind of test on the bearing test machine, it is necessary to supply oil to the case through the squirts which have been described above as being used for warming up. The squirts are arranged in line with the ends of the bearing so that they supply oil where it can seep into the bearing clearance.

In preparing for the sticking test, the bearing is run in as before, but getting the speed up to 2450 r.p.m. After running long enough at this speed so that all conditions are stabilized, the crankpin oil supply is cut off and a stop watch started. Here again frequent checks must be made on the familiar material to make sure no conditions of the test have changed so as to affect the results.

Fatigue testing can also be carried out. The main deficiency of the straight copper-lead material which caused it to be abandoned for engine use is its lack of fatigue strength. Bearing loads much above 3000 lbs. per sq. in. are likely to cause fatigue cracks to develop in the bronze and eventually small pieces of the bronze will separate from the steel back. Fig. 4 shows the central portion of a test weight which has been drilled near the bore in order to weaken the

Fig. 6. Typical test results on a bronze bearing.

REPORT OF DIVE TEST

Test No.	120.
Bearing	Split, steel back; PWA-224, hardness 49-58 V.P.N. (25 lead, 3 tin, 72% copper).
Clearance	0.008 on diameter.
Crankpin	SAE-2512. This pin had been used on tests Nos. 118 and 119 with no seizure; good condition.
Test	Dive; 3-hr. run-in to 2000 r.p.m., then speed increased 50 r.p.m. every 2 min.
Result	Seized at 3250 r.p.m. Free lead smeared over a strip 5/8 in wide. Crankpin burned in corresponding position, unfit for further use.

weight and increase the flexure of the bearing metal. This enables fatigue cracks to be developed at a moderate load in less than 5 hrs. The particular weight shown had the weakening hole drilled so near the bore that cracking also took place in the weight. It is not necessary to accelerate the fatigue test to this extent and the weight can be used without weakening holes, as illustrated in Figs. 2 and 3.

It is obvious that if the test machine is designed to accommodate the largest bearing which will be tested, smaller ones can be used at any time by fitting the appropriate crankpin, and if necessary, end washers. The machine described simulates the bearing loading of a radial engine. In the development and testing of bearings, however, it seems likely that this kind of testing is just as useful as any other kind of loading. Certainly in the comparison of different metals this type of load application is all right.

Troubles

It is not intended to give the impression that this piece of apparatus is so perfect in design that it automatically gives the correct answers without effort on the part of the investigator. This would be far from the truth since many months of effort were spent in getting the bugs out of the original machine. It was soon learned that the accuracy necessary was the same as that required in an actual aircraft engine, and that limits or fits that would be acceptable in ordinary machinery are not good enough.

The crankpin must be accurately parallel with the front extension of the shaft. Otherwise, the master weight will drift toward one end or the other and cause excessive wear on the end face of the bearing. The master weight should be in dynamic balance by itself and the weight-crankshaft-counterweight system should also be in balance.

In the early running of the machine the torque arm exhibited considerable vibration. After sufficient investigation it was found that the torque arm gear was not accurately aligned with the center of rotation of the crankshaft. Improving the fit of the rear cover and locating it with dowels did not make sufficient improvement, so that a small ball bearing was added as a pilot bearing between the rear crank arm and the torque arm gear. One of the two bearings which located this gear was then removed and the other bearing given sufficient clearance so that the gear could follow around with the crankshaft. While the motion at this point is quite small, this change has been sufficient to give a perfectly steady torque arm so that a spring scale can be used without the need of any dashpot or other damping arrangement. It is hardly necessary to point out that unbalance of the weight will produce torque arm vibration.

The machine was originally built with shielded ball bearings, both on the crankshaft and on the pinion. Lubrication was taken care of by grease nipples. This construction was intended to allow the use of dirty oil in the case without having it destroy the bearings. It was found that this type of lubrication was not sufficient for the pinion bearings and accordingly oil holes were provided in the crankpin and the rear crank arm to get a constant small feed of oil to these bearings. As a further improvement a larger size bearing has been used than originally provided so that reasonable life is now obtained on these parts.

Oil scavenging trouble is not confined to engine crankcases, but can also be experienced in test rigs. The use of too small scavenging pumps, allowing oil to accumulate in the housing, not only causes excessive power consumption and heating of the oil, but also results in excessive vibration of the torque arm. Fortunately, this trouble is easily cured by complete scavenging.

While it should be evident that the bearing should be just as carefully fitted as though it were going into an engine, with a straight round bore and the proper diametral and end clearances, this necessity must be made plain to the shop. Knowing that the bearing will be ruined in a few hours of running, there may be a tendency to slight the fitting. It is best to have one of the regular shop inspectors measure each bearing after it has been fitted into the master weight and make a record of the essential dimensions. In this connection the metallurgical condition of the master weight is of considerable importance. It was found in our early work that the bore of the master weight was different after every test. This was due to internal strain which was gradually being relieved by repeated heating and vibration, and was overcome by properly stabilizing the material of the weight after rough machining.

The troubles encountered in the development of this test rig have been no more numerous than must be expected in connection with any new piece of apparatus. As it is now set up, the machine is a useful addition to the testing laboratory and saves an immense amount of time in the testing of new bearing material.

A Lead-Tin-Arsenic Wiping Solder

by EARLE E. SCHUMACHER and G. S. PHIPPS

Metallurgists, Bell Telephone Laboratories, New York

A very interesting illustration of the beneficial effects of what was once regarded as a possible impurity in an alloy is found in this article. Small amounts of arsenic in the conventional lead-tin wiping solder have been found to bestow desirable properties and to greatly improve the older alloy.—The Editors.

IMPORTANT LINKS in the physical structure required for satisfactory telephone operation are the gas-tight joints connecting the lead sheaths which protect the circuits within from the vagaries of the climatic environment. Some fourteen or more wiped joints occur in every mile of lead-sheathed telephone cable, and in making these joints from one to two million pounds of solder are used per year. To join cables, a lead sleeve of sufficient diameter to accommodate the bundle of spliced wires is slid in place at the junction, the ends of the sleeve are beaten to conform to the circumference of the cable, and an air tight and mechanically strong joint is formed at each end of the sleeve by molding a solidifying mass of solder into the desired shape. This last step is called the wiping operation.

Composition of Wiping Solders

The making of a successful wiped joint depends upon a satisfactory composition in the solder and considerable skill on the part of the splicer. The two factors are inter-related in that the more dextrous operators can produce satisfactory joints with compositions which could not be shaped by the average operator. The most satisfactory composition for a wiping solder from practical tests has been found to be about 38 per cent tin, 62 per cent lead. A solder containing 40 per cent tin also possesses satisfactory handling qualities and is used to some extent. If the tin content is much above 40 per cent the workable temperature range in which the solder is plastic becomes too limited for practical handling. The plastic range can be increased by increasing the lead content above 62 per cent but then it is found that the joint becomes coarse-grained and porous. The highest practicable lead content is of course advantageous from an economic standpoint.

The impurities allowable in a wiping solder are also closely controlled since in general small percentages of most impurities have been found to have a harmful effect upon the handling character of the solder or the properties of the joints. One exception, which has hitherto not been recognized, is arsenic whose beneficial effects in small quantities are discussed in this paper.

An engineer would prefer to interpret the handling of a wiping solder in terms of basic properties which can be measured in the laboratory. Such attempts[1] have been made but with only limited success since not only does the wiping process itself not admit of scientific measurement but also the basic properties related to the process are difficult to determine and are of restricted practical bearing. These difficulties arise because a complex solid-liquid system is involved, and during most of the time of wiping the joint the system is far from being in an equilibrium condition.

Characteristics of a Wiping Solder

Experience has shown however that a wiping solder should possess certain general characteristics which are enumerated below, although in many instances the characterization cannot be extended beyond a qualitative statement:

1. The temperature at which the solder begins solidification should be lower than the temperature of beginning melting of the cable sheath and sleeve. The temperature of beginning solidification for the 38-62 tin-lead solder is 240 deg. C. while the lead alloy sheath begins to melt at approximately 310 deg. C. Since with this solder no trouble is encountered with melting sheath it appears that a 70 deg. differential is satisfactory.
2. The solidification range of the solder should be such as to provide, during cooling, an ample forming period between the time when enough primary lead has precipitated to give sufficient body to permit forming to begin until the mass is too solid to manipulate. In the 38-62 wiping solders the solidification range is approximately 60 deg. C. while the forming range is about 40 deg. C.
3. The tendency for the joint to drain or slip and break apart during wiping should be a minimum. These properties are associated with surface tension and plasticity. The desired condition is sometimes referred to as a "buttery" texture.
4. The solder should readily wet and alloy with the parts to be joined. This implies a freedom from non-reducible oxides in the solder and a minimum in the tendency to form reducible oxides. Suitable

non-corrosive fluxes are used to clean the surfaces being joined and reduce the oxides which cannot be entirely excluded from the melted solder. To facilitate handling, the solder should not adhere to the splicers' wiping cloths.

5. The solder should be such that the strength of the joint formed should be equal to or greater than that of the parts being joined. The joint must also be gas tight. This property is secured through a fine texture in the solder and freedom from draining of the lower melting constituents. The test for porosity of a joint is simple. A positive gas pressure of from 6 to 9 lbs. per sq. in. is applied inside the sleeve and soap-suds are then painted on the joint. Observation of the soap-suds will then show whether or not the joint is porous.
6. The health hazard under normal conditions of use should be negligible.

Effect of Arsenic

An investigation was made of modifications of the lead-tin type wiping solder to produce a solder which more fully meets the practical requirements than does the present composition. Through the addition of 0.1 per cent of arsenic, substantial improvements have been achieved in certain of the characteristics. The nominal composition of an alloy which shows this improvement is tin 37.25 per cent, arsenic, 0.1 per cent, and balance lead. The effect of arsenic manifests itself at percentages as low as 0.04 per cent. Amounts much over 0.1 per cent should be avoided because of a tendency to segregation at the higher percentages. As the tin is reduced below the recommended percentage, the difficulties in producing a satisfactory joint increase. There is the possibility however that a lower tin content can be tolerated but definite conclusions await further substantiation in subsequent investigation.

Although the percentage of arsenic in the new solder is relatively small it has two important beneficial effects: The amount of dross formed on the arsenic-bearing solder is but a fraction of that experienced in the ordinary lead-tin solders. The practical advantage is that less time need be spent in skimming the molten solder in the melting pot, and there is less possibility for the inclusion of dross in the finished joints. The presence of dross in the wiped joints is to be avoided because of its possible contribution to porosity.

Arsenic Benefits Grain Size

The second beneficial effect of arsenic is related to the grain size in the solidified alloy. This is illustrated by the photomacrographs, Figs. 1 and 2, which compare the grain structure of a lead-tin solder and an arsenic-modified solder which have undergone similar handling and cooling treatments. The arsenic-bearing solder exhibits a finer and more uniform texture. The finer texture is associated with improved handling characteristics and freedom from porosity in the finished joint. The texture of the solder is more buttery in the wiping process and there is less tendency for the lower freezing constituents to drain from the partially finished joints than with the lead-tin compositions. Practically, this provides for the splicer a longer forming range, although the solidification range is materially the same as for the corresponding unmodified alloy.

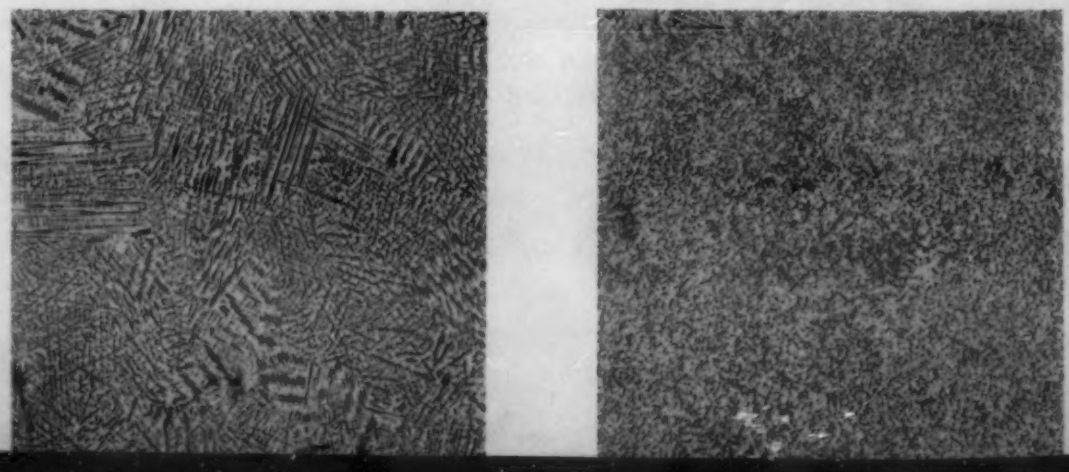
Although the mechanism by which arsenic reduces the size of the dendrites and refines the grain of wiping solder has not been definitely established, it seems probable that it either provides new and more numerous nuclei of crystallization around which the primary lead precipitates, or imposes barriers against the growth of the primary lead crystals or both. Arsenic forms a compound, Sn_3As_2, with tin and it is probable that this constituent is responsible for the mechanism postulated. In slowly cooled solders this compound is discernible beginning at approximately 0.1 per cent arsenic. With a greater number of precipitated crystals present, a greater surface is made available to which the molten eutectic may cling, producing a readily formable mass.

Laboratory observations on the solder have been verified by field tests in the Bell System. The arsenic-bearing solder is handled in the same way as the ordinary lead-tin compositions. Joints have been wiped on large and small aerial and underground cables and in difficult situations involving large branched joints. The consensus of splicers from several different localities is that the solder possesses handling properties superior to those of the lead-tin compositions. These joints in all cases were pressure tested after wiping and found to be sound.

Regarding the possible health hazard involved in using the new solder, tests have been made to determine whether arsenic or arsenic compounds would be volatilized from this alloy under the conditions encountered in practice. These tests gave entirely negative results and showed that no additional hazards would be introduced by substituting arsenic-bearing solder for standard solder.

Reference

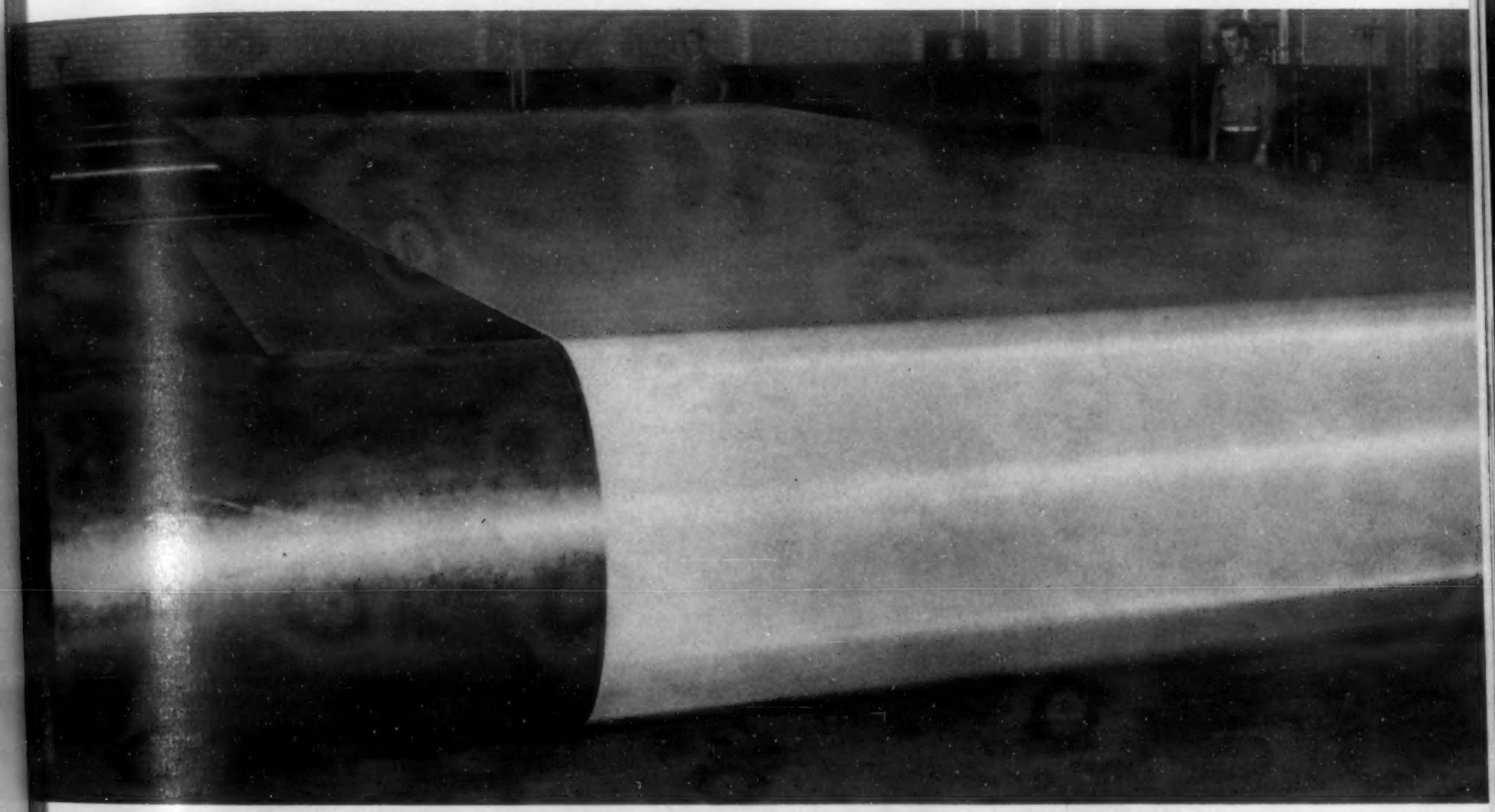
[1] Some Physical Properties of Wiping Solders, D. A. McLean, R. L. Peck, Jr., and E. E. Schumacher, *Journal of Rheology*, Vol. 3, Jan. 1932, p. 53.



Figs. 1 and 2. Photomacrographs of a nominal 38 per cent tin—62 per cent lead wiping solder showing the grain refining effect of the addition of arsenic. The samples were slowly cooled from 300 deg. C. Specimens etched with a mixture of 4 parts of glacial acetic acid and 1 part of 30 per cent hydrogen peroxide. Magnification, 4 diameters. Fig. 1 (left) is without arsenic and Fig. 2 (right) is with 0.1 per cent arsenic.

Metallurgical Control in the Fourdrinier Wire Industry-II

CONCLUDED FROM FEBRUARY



Stretching the finished seamed Fourdrinier wire. As the wire passes over these rolls, every inch of the material is carefully inspected. A definite stretch is given to each wire to bring it to the exact measurements for the paper machine on which it is to be used. This treatment also imparts a beneficial rigidity to the wire.

by D. C. DILLEY

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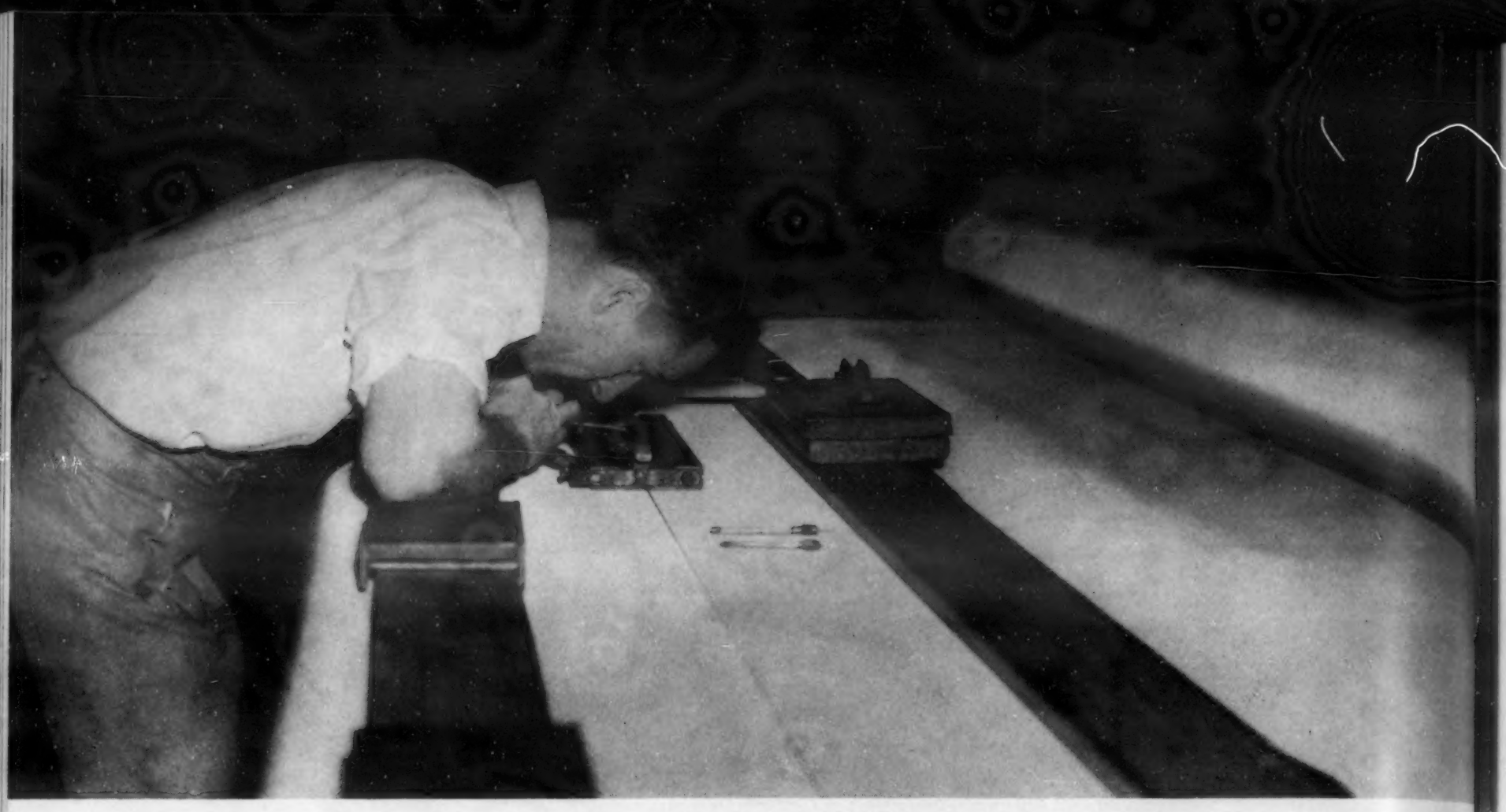
Seaming

When the cloth has been cut to proper length the two ends must be joined to form the Fourdrinier wire. The seaming of the wire perhaps requires more careful manipulation by the operator than does any other single operation. Because any variation in opening between the shoot wires at the seam will cause non-uniform drainage of the pulp, with the consequent marking of the paper being formed, measurements must be taken, in the shop, all during the seaming operation by means of measuring microscopes, to insure a uniform spacing of the wires at the seam.

There are four general types of seams now in use: The all-sewed seam, the soldered and sewed seam, the silver or hard soldered (brazed) seam,



Seaming of finished wire cloth to form a Fourdrinier wire. The operator works with the aid of special magnifiers. The two faces of the cloth must be joined perfectly, with no flaws or irregularities.

and the welded seam. Sewing was of course the original method of joining wire cloth end-to-end. Later the introduction and perfection of hard soldering methods using silver soldered (or brazed) seam, was developed. This field of research alone has kept the industry busy for many years perfecting a joining link which will approach the characteristics of the wire cloth in the body of the wire. The laboratory must test examples of seams to insure normal microstructure of the soldered joint. The penetration of the solder into the shoot wire and into the warp wire will change according to the temperature of the welding flame. For this reason careful control must be maintained on the gas lines which feed to the micro-welding torches. Suitable clamps and protecting plates direct the tip of the brazing or welding flame to the work and prevent heating of the wire mesh near the seam. The fluxing of the braze is of primary importance in insuring a firm bond between solder and wire. Compounds of boron and also the fluoride salts make the best cleaner, which may be applied in the form of a wet coating.

The most remarkable development in the seaming of Fourdrinier wires has been the application of gas and electric welding to the joining of warp wires. Under this operation the two ends contact each other. The torch is then applied and the two wires melt at their point of contact to form one continuous strand. The control of the flame temperature in this operation is of utmost importance. When one considers the rapidity with which the seam can be introduced into a wire, as many as 14,000 unit welds being made in one 8-hr. day by a single operator, the fruits of industrial research will be appreciated. It was only through hours of tedious development that the art of welding could have been perfected in this manner.

Testing the Product: Wire Life

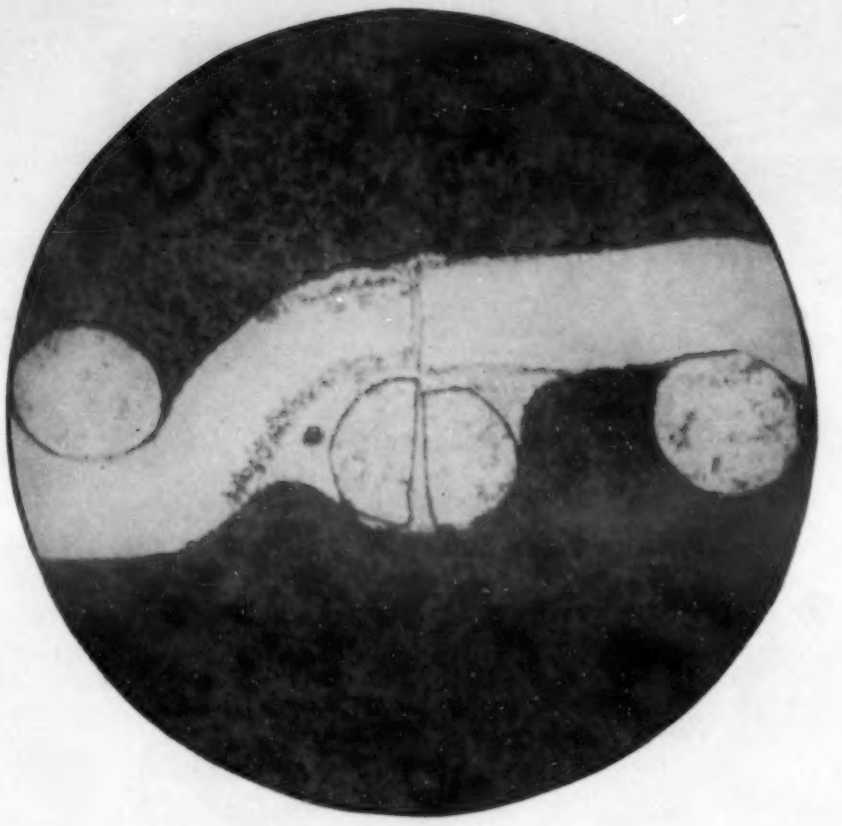
The manufacturers of Fourdrinier wires realize that probably the greatest single destructive influence contributing to wear on the paper machine is the abrasive effect caused by the particles of silica and china clay which becomes embedded in the tops of the suction boxes.[15] However, no test has been developed which will accurately predict the life of any particular type of Fourdrinier wire. Ecourrou[7] and others have suggested mechanisms for testing resistance to abrasion, but these tests do not evaluate the combined influence of reverse bending and abrasive wear, although they may be run in actual mill waters, or aluminum sulphate solutions. The dynamic bend test for both single strands and for strips of woven wire gives an excellent indication of the resistance of wire to reverse bending. Seams are also tested in this manner to determine what percentage of normal unseamed wire life, a seamed specimen will be capable of yielding. There is no test which will indicate mill life, for no two mills subject the Fourdrinier wire to like conditions of wear.

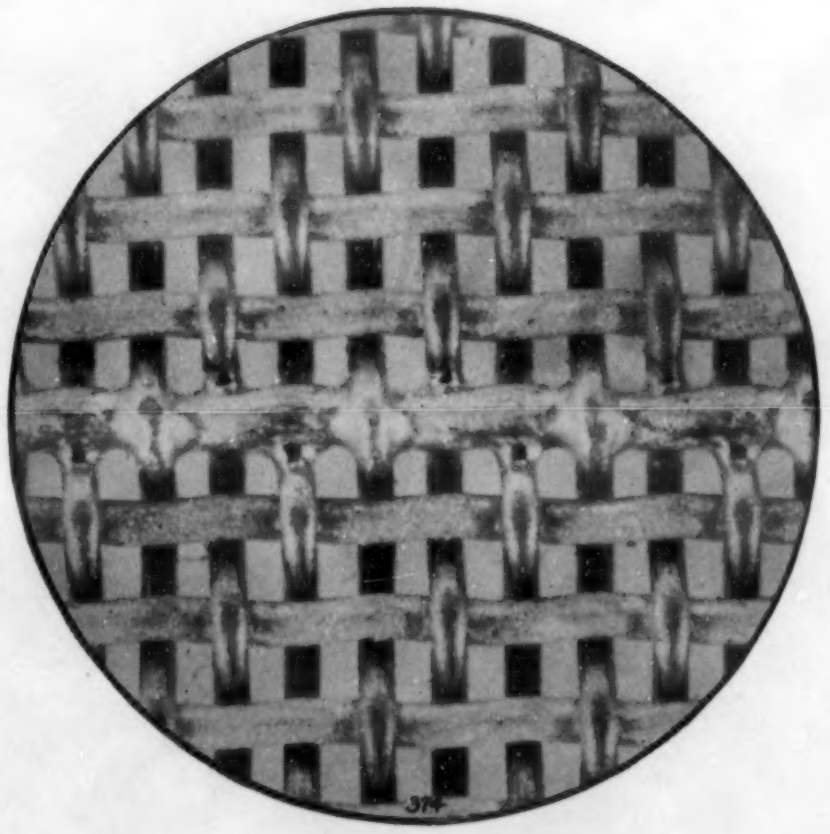
The new high speed paper machines, while showing less tendency to abrade the wire on the suction boxes, give rise to new problems of tensile loads and many other peculiar operating difficulties which do not appear in the slower model machines. For

instance, the substitution of bakelite, plastic, or metal, for end grain maple, for suction box tops in some machines has changed the type of wear experienced from the suction boxes. Such factors as poor alignment of the rolls on the paper machine, improper crown of the breast or couch rolls, too high a suction on the boxes, and roll bearings which offer a drag against the free movement of the wire, denting and creasing of the wire when it is installed, or by stock bumps, are all factors beyond control of the wire manufacturer, and which materially affect the life of the wire. These influences are, of course, almost impossible to check or duplicate in laboratory life tests, and yet in many cases, they may be the determining factor in the record of any given wire.

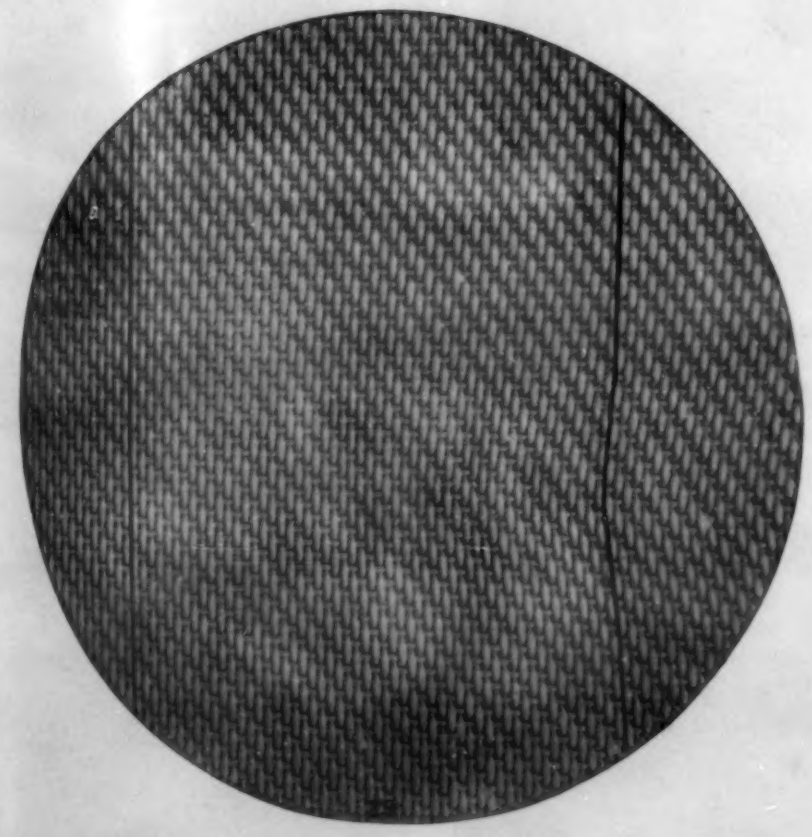
In this connection it should be pointed out that the wire has its most rigid inspection on the stretcher operation following seaming. Every inch of the cloth is inspected as it passes over the stretcher roll. Following this, the wire is removed from the stretcher by moving out both rolls of the stretching mechanism. A final check on measurement is then made before the wire is wound on three poles. The ends of the poles are securely tied and nailed to end blocks to prevent shifting of the wire, and the poles and wire are wrapped in cellulose wadding before being lowered into the box.

During transit, the wire may be severely damaged by end shock or dropping of the box. End shock may cause slippage of the Fourdrinier wire on the poles generally resulting in a series of small parallel puckers distributed across the wire where it is pinched between the bottom poles. The dropping of the wire box on the other hand may cause a series of crow foot marks running down the center of the wire. Both these types of damage are quite different from a pole mark which can be caused by careless removal of the poles from the wire. A pole mark generally is formed outward and is in the nature of a small streak running almost parallel

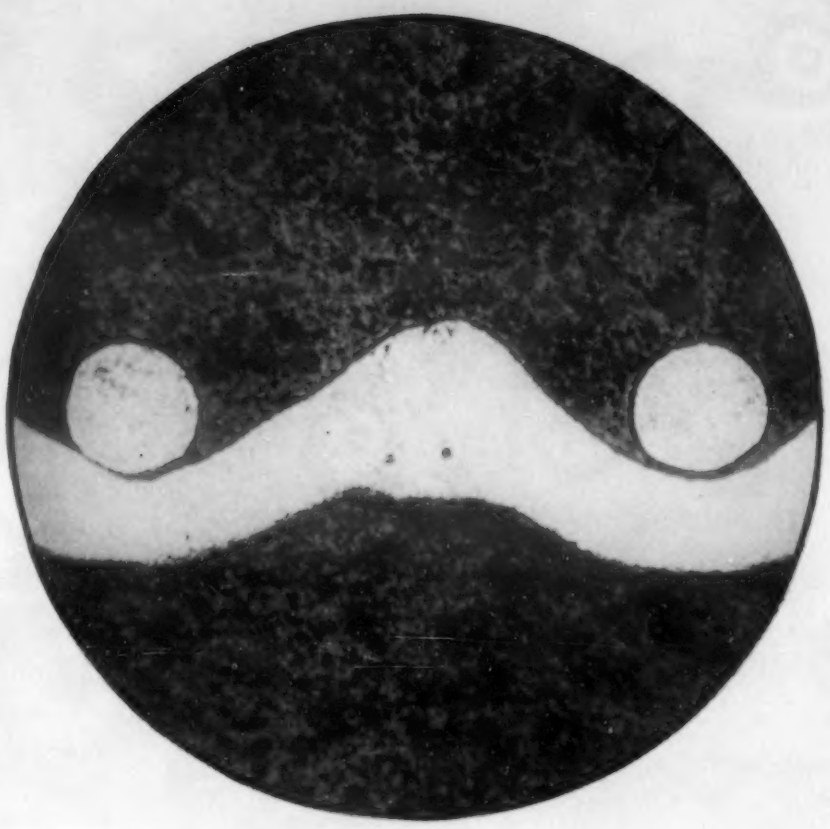


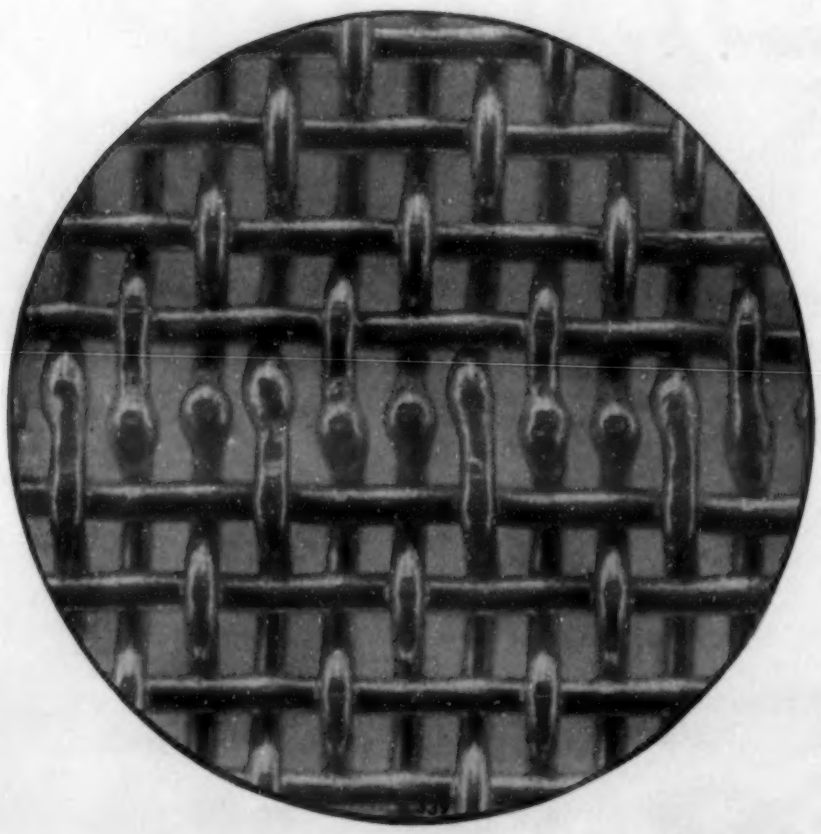


Silver soldered type Fourdrinier seam. Upper photo is a section through the warp wire at the seam at 100X. The half-sectioned brass shoot wires are fixed to the bronze warp wires by the silver solder which forms the fillets shown in the illustration. The lower photo is a macro-view, at 30X, showing the appearance of the seam from the top of the wire.



Showing a wrinkled wire, used and damaged in transit. 2X.





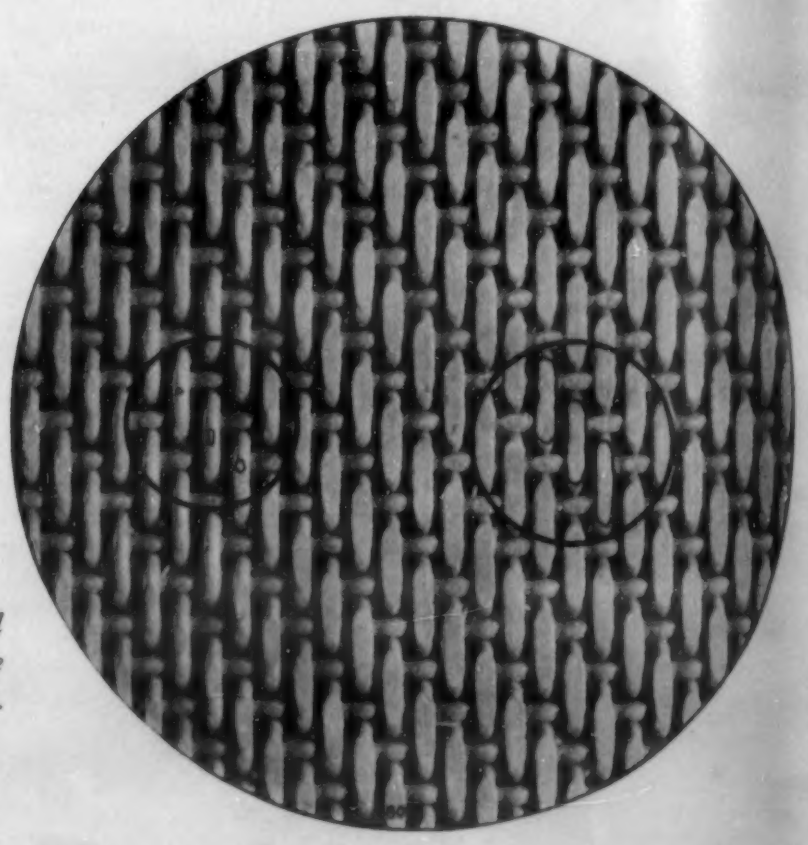
Gas welded, "dot-type," Fourdrinier seam. Upper photo shows the structure of the fusion welded bronze warp wires, longitudinal section at 100X. The shoot wires do not become part of the seam in this case. The lower photo is view of the surface at 30X.

to the shoot wire but generally varying somewhat in its direction. These damaged areas like any small indentation in the wire, are apt to wear through causing early failure. Most manufacturers prefer to be advised when the mill discovers damage of this nature so that the wire can be returned and the damaged spot removed rather than to have the paper mill run the wire, in such condition, or attempt to remove the spot themselves.

Effect of Seasons

In the case of certain paper mills, wire life has been noted to be abnormally short in the early spring and summer months. Several investigators have attributed this to the prevalence of organic acids in stream waters, probably caused by the decay of vegetable matter and plant life in the streams in warm weather. Likewise, some mills have noticed unexpectedly low wire life, which probably may be traced in part to the high hydrogen sulphide content of the natural waters used by the mills, in certain localities. The use of all bronze Fourdrinier wires has done much to avoid these seasonal, and natural, corrosive conditions. The wire manufacturers have pointed out that the bronze alloys are much less susceptible to corrosion, and corrosion cracking, and in many instances will more than pay for the additional premium on price by the added satisfaction in performance which they can give to the paper mill. It will be only through extended research in following out the individual problems such as these that any great improvements will come to the production of Fourdrinier wires. The paper mills and the wire manufacturers must work hand in hand in observing the operation of the Fourdrinier wire.

In recent years, when claims have been made on wires because of short life on the machine, it has been the practice for the manufacturer to ask for the return of the damaged or failed wire. Mills at



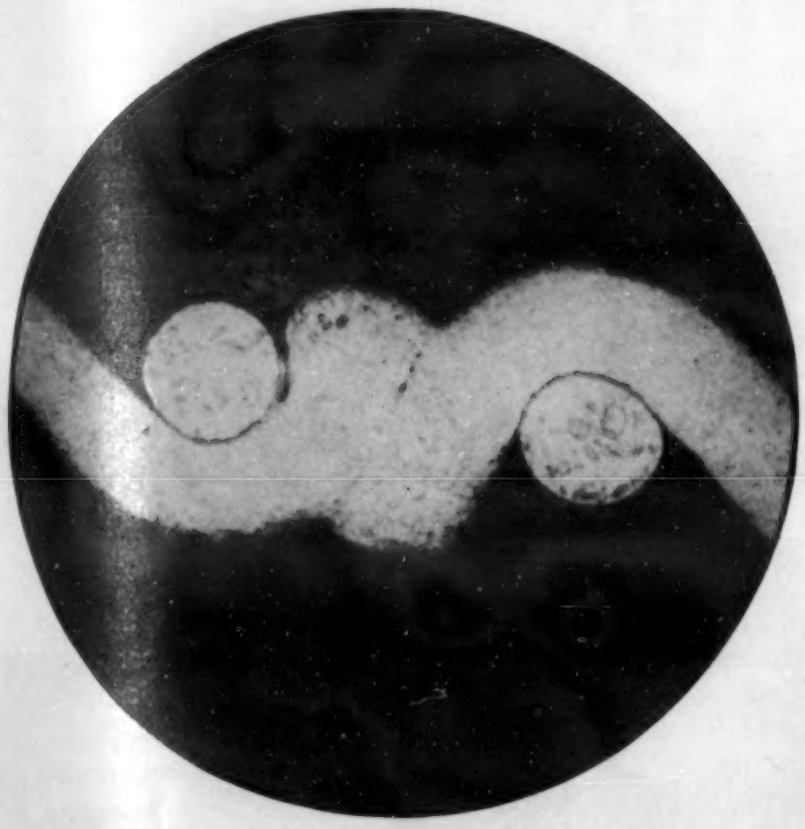
Close up view of a wrinkled wire which was used. Note the irregular wear on warp knuckles. 15X.

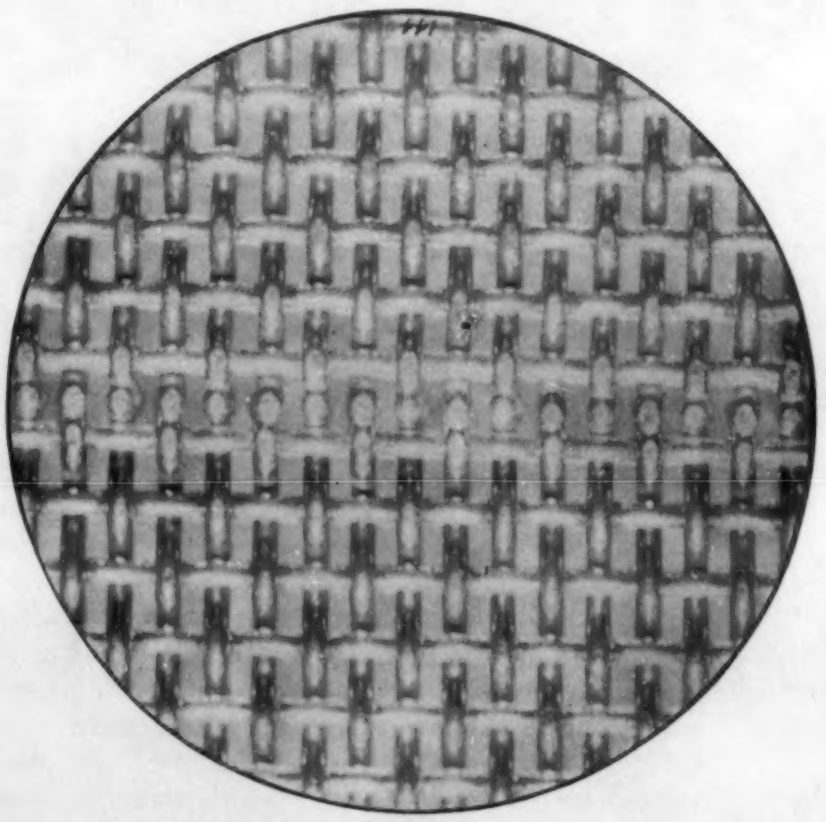
first were reluctant to accept many of the conclusions brought out by the manufacturer regarding the cause for failure. The paper mill operators must realize the real value the wire manufacturer gains from the inspection of these used wires, and that, through this medium of exchange of comments and ideas, the greatest strides may be taken in improving wire life.

The manufacturers of the Fourdrinier wire appreciate this fine cooperation which in recent years has indicated a trend to greater interest in these problems on the part of the paper manufacturers. They look forward in the future to a new spirit of cooperative interest in the hope that this may be the groundwork towards the development of a better product.

Note: This article, Part I of which was published in February, is adapted from a paper which has been submitted to the Technical Association of the Pulp and Paper Industry and which we have been permitted to use through the courtesy of that organization. The paper was scheduled on the program of that society's February convention in New York but was not pre-printed.—E. F. C.

Gas welded Fourdrinier seam used in regular weave wire cloth. This seam probably comes closer to the appearance of woven cloth of any seam. The lower photo is a longitudinal section through the bronze warp wires which are butt-welded at the seam. The photo at right is a view at the surface at 30X.





Some Oxygen-Free Coppers

— Annealing and Drawing Characteristics

by SIDNEY ROLLE and H. M. SCHLEICHER

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IN 1927 WHEN WEBSTER, CHRISTIE AND PRATT delivered their first paper on "Some Comparative Properties of Tough-Pitch and Phosphorized Copper,"[1] oxygen-free high conductivity copper, containing no residual deoxidants which might affect the electrical conductivity was not available to the trade. However, such a copper (OFHC) was put on the market early in 1932, and within less than a year was being used in commercial quantities by many fabricators here and abroad. The authors of the paper just cited recognized the importance of this commercially new kind of copper, and after investigating its properties, presented a second paper[2] in which they compared the properties of four kinds of copper: Lake tough-pitch, electrolytic tough-pitch, phosphorized and OFHC (oxygen-free high conductivity electrolytic).

A few years later the producers of OFHC copper were called upon to furnish a copper which would combine the desirable characteristics of OFHC with those of phosphorized copper. Such a copper would be immune to embrittlement when heated in a reducing atmosphere, would have a high reduction of area and elongation, would be free scaling, and would have a higher softening temperature than OFHC copper. The fabricators indicated that they wanted an oxygen-free copper which would be produced from electrolytic copper cathodes under the same precise control of atmosphere and temperature as used in the production of OFHC[3] and without the use of metallic deoxidants, but containing from 0.015 to about 0.025 per cent phosphorus. Accordingly, the producers of OFHC, the Oxygen-Free Copper Department of the United States Metals Refining Co., (now called The Scomet Engineering Co.) developed and installed equipment to provide means for adding definite amounts of phosphorus to the molten oxygen-free copper before it enters the molds, and the resulting castings, such as billets and cakes, would contain this same predetermined amount of phosphorus. It should be emphasized here that in the process[3] used for making OFHC copper, the metal is protected from the atmosphere from the time it leaves the deoxidizing unit in molten form until the solidified castings drop out of the bottom of the water-cooled molds. Consequently, the phosphorus is not oxidized, but remains in combination with the copper (probably as a phosphide) and practically all of it is available to give the copper the properties for which it is added.

The present investigation is a continuation of the work done so admirably by Webster, Christie and Pratt, its purpose being to obtain similar data for other types of copper, such as OFHC containing phosphorus (hereinafter called OFHC + P) and regular phosphorus deoxidized copper. Inasmuch as a complete analysis was not made on the particular sample of OFHC copper which was previously investigated by these authors, another sample has been included in the present work.

Procedure

The present investigation was conducted in the laboratories of the Bridgeport Brass Co., Bridgeport, Conn., along the same lines as were the two previous ones, but besides tests on rods, tests were also made on tubing fabricated in the conventional manner, in order to meet the suggestions of those who claimed this to be desirable because phosphorized copper was used almost exclusively for tubing, and in this way light would be thrown on the effect of the form of the copper under test.

A description and the analyses of the three kinds of copper used in the present investigation follow:

1. *Phosphorus Deoxidized Copper:* This is made from electrolytic copper to which phosphorus is added in sufficient quantity to deoxidize the metal and leave a residuum of about 0.020 per cent P. The term "Phosphorized Copper" as used in this paper refers only to copper produced in this manner, and not to OFHC containing phosphorus. This copper must not be confused with the Phosphorized Copper studied by Webster, Christie and Pratt; that material was not oxygen-free and contained only 0.009 per cent P.

2. *OFHC + P:* This is made by adding phosphorus to molten OFHC Copper. The OFHC is oxygen-free and, therefore, only enough phosphorus is added for the specified content (usually about 0.015 per cent), none being required for deoxidation.

3. *OFHC:* This copper is produced by a patented process[3] from electrolytic copper cathodes. It is oxygen-free, contains no residual deoxidant, and by keeping the impurities below certain limits, its electrical conductivity is high.

Table I shows the analyses of these three coppers. The analyses show that all three kinds of copper are of high purity. None of the impurities is present in abnormal amount.

The billets of phosphorized copper were taken from stock at the Bridgeport Brass Co. Those of the two types of OFHC copper were obtained from stock of The American Metal Co., Ltd. Several billets of each kind were analyzed in order to be sure that those used were normal in all respects. The complete details of the procedure used in making the tests follow:

A. Preparation and Testing of Rod Samples

Billets Nos. 1, 3 and 5 (3 in. dia.) were heated at about 825 deg. C., and then hot rolled to 0.810-in. dia. rods; then annealed at about 600 deg. C. for 2 hrs. The rods were then pickled preparatory to cold drawing in two stages to 0.5 in. dia. rods, a total reduction of 62.5 per cent. The resulting coils were then divided into two equal portions, (a) for making the annealing tests, and (b) for the drawing tests.

(a) Two samples, each 8 in. long, were annealed for 1 hr. in an electrically heated muffle at the following temperatures (Centigrade):

190°, 220°, 250°, 300°, 400°, 500°, 600° and 700°

Two check tests were made at 500, 600 and 700 deg. C.

(b) The 0.5-in. dia. rods were cut into 3 ft. lengths and then annealed in an electrically heated muffle at about 500 deg. C. for 2 hrs., pickled and drawn to sizes diminishing by about 0.03-in. as shown in Table II. The procedure followed closely that given by Webster, et al in their first investigation[1].

TABLE II

Final Size Inches	Total Reduction Per cent
0.499	0
0.468	12.0
0.432	25.1
0.408	33.0
0.372	44.2
0.341	53.3
0.307	62.1
0.279	68.7
0.248	75.3
0.218	80.9
0.188	85.8
0.158	90.0

Tensile strength, percentage elongation in 2 in. and percentage reduction of area determinations were made on samples cut from each of the rods shown in the table, and turned down to an area approximately 50 per cent of the original area.

B. Preparation and Testing of Tube Samples

Billets Nos. 2, 4 and 6 (3 in. dia.) were pierced in a Mannesmann machine to shells 2.50 in. O.D. x 0.250 in. wall. One-half of each shell was drawn without anneal to 0.875 in. O.D. x 0.065 in. wall, a reduction of 90.5 per cent. The other half of each shell drawn without anneal to 1.50 in. O.D. x 0.100 in. wall, annealed at 500 deg. C. for 2 hrs. and then redrawn without anneal to 0.875 in. O.D. x 0.065 in. wall, a reduction of area of 62.5 per cent.

TABLE I—ANALYSES OF THE THREE COPPERS

	Phosphorized Billet No. 1	Phosphorized Billet No. 2	OFHC + P Billet No. 1	OFHC + P Billet No. 2	OFHC Billet No. 1	OFHC Billet No. 2	Method of Analysis
Phosphorus	0.021	0.020	0.013	0.015	.....	.....	Chemical
Sulphur	0.0027	0.0042	0.0034	0.0041	0.0040	0.0042	Chemical
Arsenic	0.0008	0.0008	0.0004	0.0004	0.0004	0.0004	Chemical
Antimony	0.0015	0.0014	0.0004	0.0007	0.0006	0.0006	Chemical
Selenium	0.0008	0.0003	0.0003	0.0007	0.0003	0.0008	Chemical
Tellurium	0.0015	0.0016	0.0013	0.0013	0.0012	0.0007	Chemical
Lead	0.0010	0.0010	0.0008	0.0008	0.0005	0.0005	Spectrographic
Lead	0.0008	.....	0.0005	.....	0.0007	.....	Chemical
Tin	0.0003	0.0003	0.0001	0.0001	0.0001	0.0001	Spectrographic
Bismuth	0.0002	0.0002	0.00005	0.00005	tr.	tr.	Spectrographic
Silicon	0.0010	0.0010	0.0015	0.0015	0.0010	0.0005	Spectrographic
Silicon	0.0004	.....	0.0003	.....	0.0004	.....	Chemical
Iron	0.006	0.006	0.002	0.003	0.002	0.001	Spectrographic
Iron	0.0005	.....	0.0012	.....	0.0016	.....	Chemical
Manganese	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	Spectrographic
Nickel	0.0015	0.0015	0.0005	0.0005	0.0005	0.0005	Spectrographic
Nickel	0.0010	.....	0.0004	.....	0.0007	.....	Chemical
Silver	0.0023	0.0023	0.002	0.002	0.002	0.002	Spectrographic
Silver	0.0028	.....	0.0024	.....	0.0022	.....	Chemical
Chromium	Nil	.....	Nil	.....	Nil	.....	Chemical
Oxygen	*	*	*	*	*	*	
Copper **	99.9655		99.9760		99.9873		
Copper ‡	99.9865		99.9890				

* None detectable under microscope at 200 ×.
** By difference, based on chemical analysis where available.
‡ Omitting phosphorus.

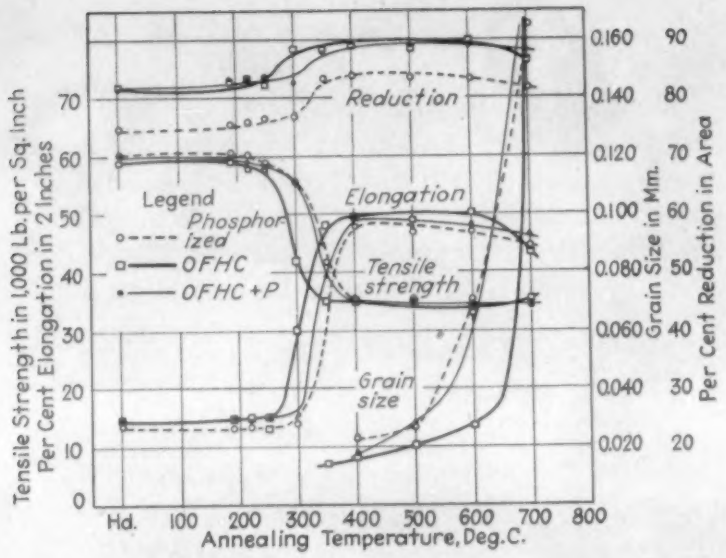

Fig. 1. Characteristic annealing curves of various kinds of copper. (Rod samples reduction 62 per cent.)

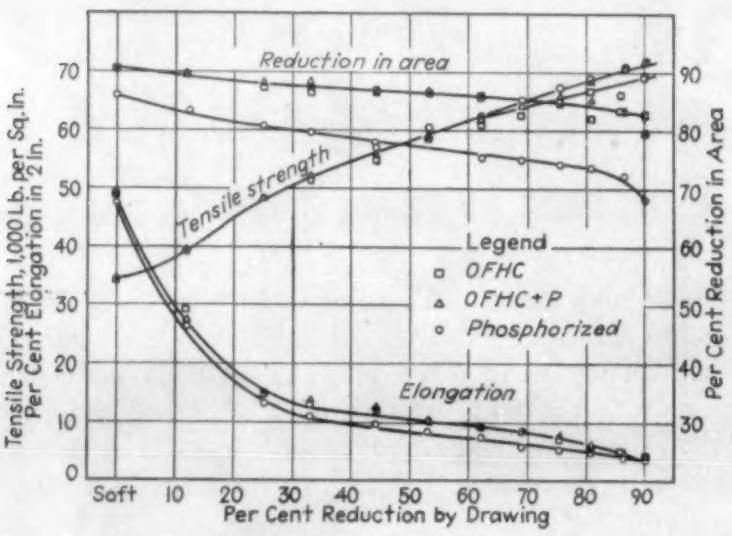

Fig. 2. Characteristic drawing curves of various kinds of copper. (Rod samples reduction 62 per cent.)

Lengths of 12 in. were cut from each piece of 0.875 in. O.D. x 0.065 in. wall tubing made from both halves of the shells and then annealed in bundles of 3 samples for 10 mins. in molten salt bath at the following temperatures C:

250°, 275°, 300°, 325°, 350°, 375°, 400°.

Tensile strength tests were made on each tube, using round nose tapered plugs at each end to support the wall. Each tube marked with four 1 in. gage marks between tapered plugs and elongation taken across breaks between 2 in. gage marks. Rockwell hardness tests made on concave (inside) surface of tubes; small 1/8 in. anvil used to support the tube.

Results

The data obtained in the various tests have been plotted as follows:

Fig. 1. Characteristic curves showing the effect of annealing on tensile strength, elongation, reduction in area and grain growth of various kinds of copper. (Rod Samples Reduction 62 per cent).

Fig. 2. Characteristic curves showing the effect of drawing on the tensile strength, elongation and reduction in area of rods of various kinds of copper.

Fig. 3. Characteristic curves showing the effect of annealing on tensile strength and elongation of various kinds of copper tubing 62.5 per cent hard.

Fig. 4. Characteristic curves showing the effect of annealing on tensile strength and elongation of various kinds of copper tubing 90.5 per cent hard.

Figs. 5, 6 and 7. Characteristic curves showing the effect of annealing on tensile strength, Rockwell hardness and elongation of copper tubing 62.5 per cent and 90.5 per cent hard, made from phosphorized, OFHC + P and OFHC copper respectively.

Fig. 8. In order to facilitate comparison of the annealing characteristics of the six types of copper investigated to date, particularly as indicated by tensile strength determinations, all the relevant curves for these tests are given on one plot.

Discussion of Results:
1. Annealing Characteristics

a) *Rod Samples, Reduced 62 per cent:* The two phosphorus-bearing coppers behaved very much alike in the annealing tests. The OFHC copper softened at a lower temperature and marked crystal growth started at a higher temperature than in the other two coppers.

It is interesting to note the part played by the incidental impurities in copper in the rise of the softening temperature obtained with phosphorus. The sum of the determined impurities in OFHC copper is about 0.013 per cent, and this happens to be equal to the percentage of phosphorus added, and presumably in solid solution in the sample tested. As indicated in Table V, the temperature for reaching complete softness is about 225 deg. C. for electrolytic tough-pitch copper, which has little impurity in solid solution; 350 deg. C. for OFHC with practically all impurities in solution, and 400 deg. C. for both phosphorized coppers with all impurities, and also around 0.013 per cent P in solid solution. Apparently the impurities in copper play an important part in the rise of softening temperature induced by the addition of phosphorus.

b) *Tube Samples, 62.5 per cent Hard:* Of these three oxygen-free coppers, those with phosphorus showed similar behavior in the annealing tests. They

resisted softening for about 50 deg. C. higher than the OFHC copper.

c) *Tube Samples, 90.5 per cent Hard:* The relative positions of the curves for these three oxygen-free coppers are similar to those of the tubes 62.5 per cent Hard, which show that while the harder tubing of OFHC copper softened at a little lower temperature than the softer tubing, this did not hold true for the two phosphorized coppers. Pilling and Halliwell[4], and Alkins and Cartwright[5] showed a marked lowering of softening temperature with increase of cold working on the copper they investigated. Perhaps the dilute alloys do not follow the same rule.

2. Grain Size

It will be noted that the grain size versus temperature curve for OFHC, as shown in Fig. 1, indicates the critical temperature is about 625 deg. C., above which the grain size increases markedly. It should be mentioned here that particular care was taken when measuring the grain size to avoid the zone of oxygen penetration.

The copper containing phosphorus showed grain growth at lower temperatures. Phosphorus may act specifically on grain growth, but it seems more likely that the total amount of material in solid solution is the determining factor. In phosphorized and OFHC + P copper, grain growth begins at lower temperatures than straight OFHC, the break coming at about 500 deg. C. At 600 deg. C., there is a marked difference between the size of the grains of OFHC and that of the coppers containing phosphorus; at this temperature OFHC grains are about 0.027 mm., whereas the grains of the other two kinds of copper are 2½ times as large. Full growth is attained in all three kinds of copper at 700 deg. C.

The data (Table III) obtained in the annealing tests for the rod at 62 per cent reduction, and for tubing at 62.5 per cent hard, are closely the same, indicating that the particular form in which the copper was tested has little, if any, influence on the softening temperature.

3. Effect of Cold Drawing

It will be noted that the curves in Fig. 2 show that the reduction of area data for the two OFHC coppers are the same throughout the range of annealing temperatures, and are markedly higher than for the regular phosphorized copper. This superiority of OFHC copper was also indicated in the earlier papers cited.

It can also be seen that OFHC copper has a tendency to remain softer in the higher range of reduction.

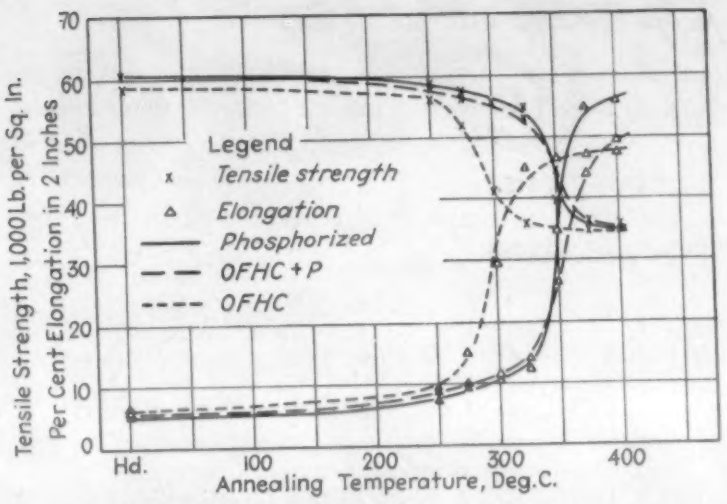

Fig. 3. Tensile strength and elongation curves of various kinds of copper. (Tube samples 62.5 per cent hard.)

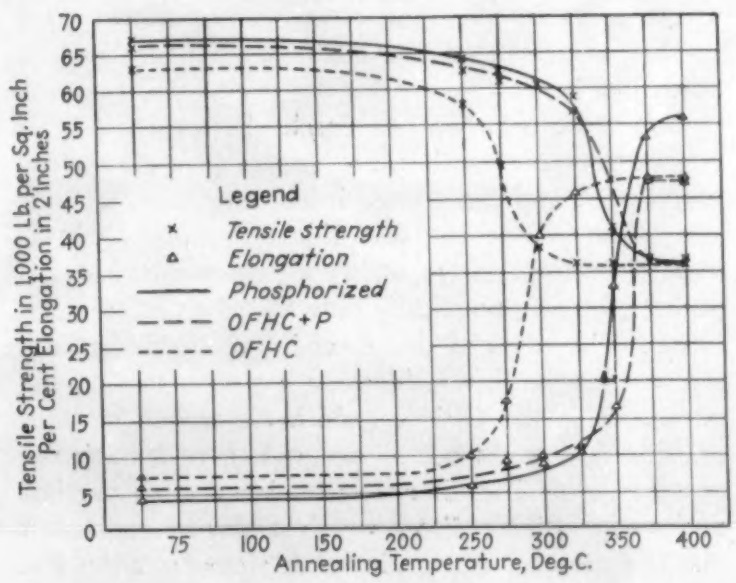

Fig. 4. Tensile strength and elongation curves of various kinds of copper. (Tube samples 90.5 per cent hard.)

TABLE III—ANNEALING DATA

Kind of Copper	Temp.	Rods 62% Hard T. S.	Rods 62% Hard % El.	Tubing 62.5% Hard T. S.	Tubing 62.5% Hard % El.	Tubing 90.5% Hard T. S.	Tubing 90.5% Hard % El.
Phosphorized ...	200	60,500	13.5	.....	...	65,500	5.0
	250	58,800	13.0	58,600	7.5	64,400	6.0
	300	55,800	14.0	55,800	11.5	60,900	9.0
	350	41,700	32.5	39,900	35.0	41,300	33.0
	400	35,400	48.0	35,300	58.0	36,100	56.0
OFHC + P....	200	59,400	14.5	.....	...	65,000	6.2
	250	58,300	15.0	57,900	9.0	62,700	6.5
	300	56,000	15.5	55,800	10.5	60,400	10.0
	350	38,000	39.5	44,700	...	47,900	16.5
	400	35,000	49.5	35,900	49.5	36,450	47.0
OFHC	200	58,800	15.0	.....	...	60,000	8.7
	250	57,700	15.0	56,500	9.0	58,400	10.0
	300	42,000	30.0	41,400	29.5	38,400	40.0
	350	35,000	48.0	35,400	46.5	36,350	46.5
	400	34,700	49.5	35,200	47.5	36,700	48.0

4. Comparison with Earlier Results

Before summarizing the results of this investigation, it would seem desirable to compare these results with those obtained by Webster, et al., as reported in their two papers.

The types of copper which were used in the three investigations are:

1. Lake tough-pitch.
2. Phosphorized copper.
3. Electrolytic tough-pitch.
4. OFHC No. 1 (used in the second investigation).
5. OFHC + P.
6. Phosphorus deoxidized copper.
7. OFHC No. 2 (used in this investigation).

Nos. 4, 5, 6 and 7 having already been described in this paper, only Nos. 1, 2 and 3 need be discussed here.

An abridged summary of the analysis available is given in Table IV. The elements not shown were present in about normal quantities and are not of particular interest.

Lake Tough-Pitch: As might be expected, this copper contains much more silver than electrolytic tough-pitch and the arsenic is also higher. The oxygen, although on the low side for tough-pitch, is more than sufficient to satisfy all the oxidizable impurities, leaving practically only the silver in solid solution. The effect of the silver in raising the softening temperature is considerably less than that of the impurities in the OFHC (which are chiefly in solid solution due to absence of oxygen), even though the percentage of silver is nearly double that of the impurities in OFHC. From which it may be concluded that the presence of certain other elements alters the effect of silver on the annealing characteristics of copper.

Phosphorized Copper: This copper differs from the phosphorus deoxidized copper used in the present investigation in two important respects: It is not oxygen-free, and the phosphorus content is much lower. The micrograph of this copper in Fig. 7, of the earlier paper by Webster, Christie and Pratt, shows no cuprous oxide, and it is probable that the molten metal was thoroughly deoxidized by the phosphorus, but picked up oxygen enough during casting to oxidize most of the residual phosphorus. Consequently, the other impurities are still in solid solution and the copper is much similar to OFHC in regard to its softening temperature and temperature of recrystallization.

TABLE IV

Kind of Copper	Copper	Silver	Oxygen	Phosphorus	Arsenic	Antimony
Lake T. P.....	99.93	.0216	.0330	Nil	.0024	.0013
Phosphorized ..	99.97	.0013	.0110	.0091	.0010	.0012
E. T. P.....	99.96	....	.0285	Nil	....	....

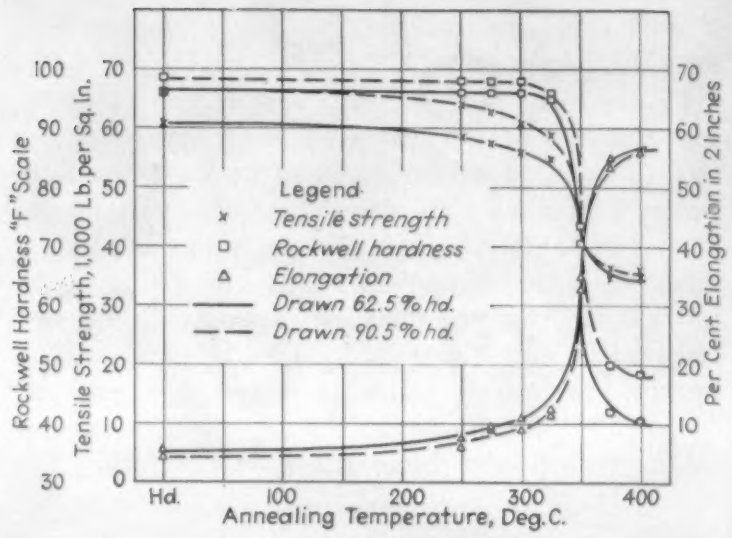

Fig. 5. Tensile strength, Rockwell hardness and elongation curves of phosphorized copper. (Tube samples.)

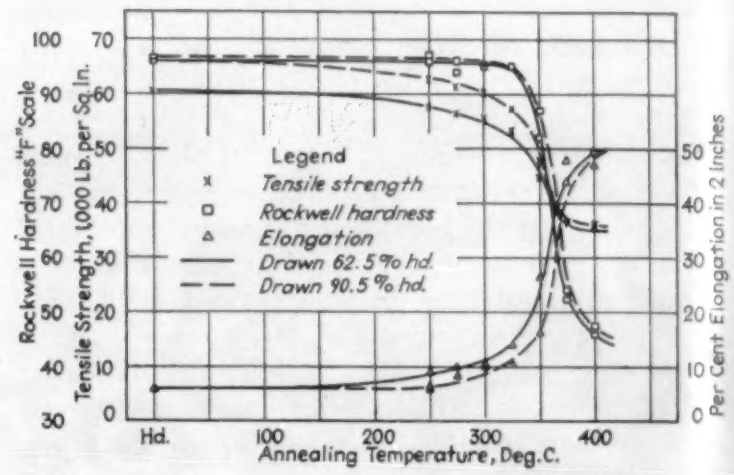

Fig. 6. Tensile strength, Rockwell hardness and elongation curves of OFHC+P copper. (Tube samples.)

Electrolytic Tough-Pitch Copper: The oxygen content of this sample is on the low side for tough-pitch copper. Practically all the impurities are oxidized and, with so little material in solid solution, the softening temperature should be relatively low. However, the softening point indicated for this copper is a little lower than would be expected for the ordinary run of electrolytic tough-pitch copper, leading to the conclusion that it was an exceptionally pure grade of metal. The analysis seems to confirm this idea.

Summary

OFHC copper softens at a lower temperature than

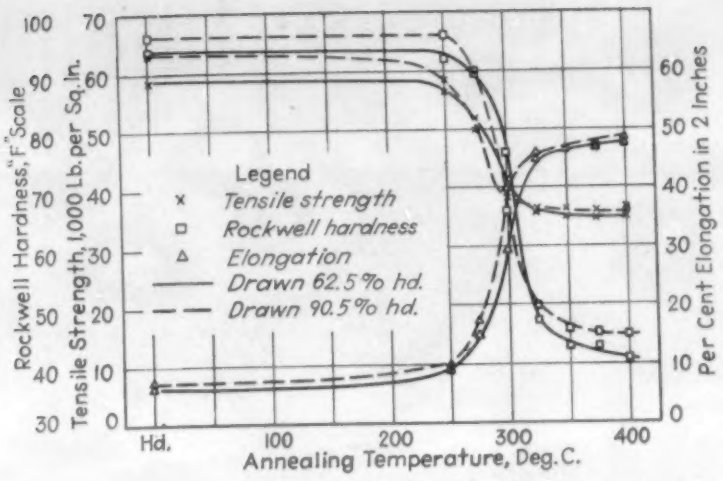

Fig. 7. Tensile strength, Rockwell hardness and elongation curves of OFHC copper. (Tube samples.)

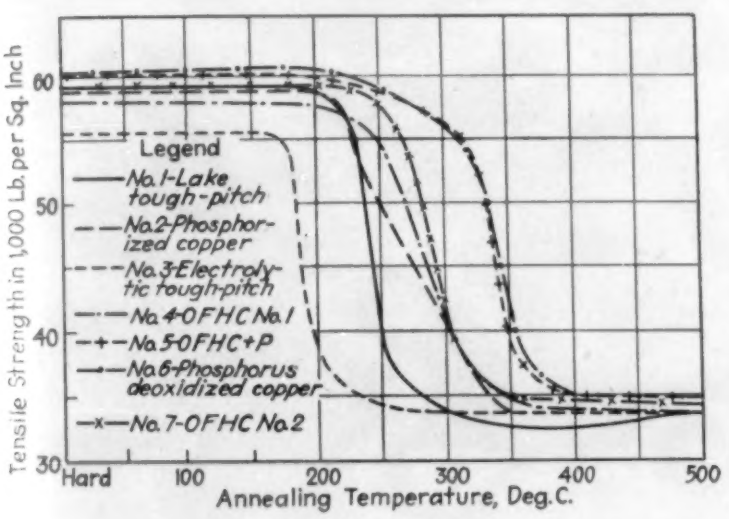

Fig. 8. Tensile strength curves of six types of copper.

either of the two phosphorized coppers which are oxygen-free. Electrolytic tough-pitch copper softens at a temperature well below any of the other coppers.

The annealing and cold drawing characteristics of the two oxygen-free phosphorized coppers are closely similar, and this fact seems to indicate that not all the phosphorus in the regular phosphorized copper is in solid solution—some of it is probably in oxidized form.

The approximate softening temperatures of the various types of copper investigated so far are given in Table V. The temperature given in each case is that at which the copper has become dead soft, or in other words, when its tensile strength has reached a minimum.

TABLE V—ANNEALING DATA ON RODS

Kind of Copper	Reduction, Per cent	Original Tensile Strength, Lbs. per sq. in.	Approximate Softening, Temp., deg. C.
Lake	62.5	57,500	300
Phosphorized (not deoxidized)	62.5	58,700	340
Tough-pitch electrolytic	62.5	55,300	225
OFHC No. 1	62.5	57,500	350
OFHC plus P	62.0	60,200	400
Phosphorus (deoxidized)	62.0	60,200	400
OFHC No. 2	62.0	59,000	350

The annealing characteristics of the three oxygen-free coppers were not appreciably affected by the form in which the copper was tested.

Increasing the reduction from 62.5 to 90.5 per cent has but little effect on the annealing characteristics of any of the coppers investigated. The only significant difference in the results obtained in the present investigation from those reported in the earlier ones is in the grain or crystal growth of OFHC copper. In determining grain size, it is essential to avoid the zone of oxygen penetration which occurs when OFHC copper is heated in air. However, this characteristic of OFHC was not so well known at the time of the earlier work.

Acknowledgments

The authors wish to thank the Bridgeport Brass Co. and The Scomet Engineering Co. for permission to publish the results of this research, and especially R. S. Pratt, of the former company, for preparing the samples and making the tests.

References

[1] *Proc.* Inst. Metals Div. A.I.M.E. (1927), page 233.
[2] *Trans.* A.I.M.E. Inst. of Metals Div. (1933), page 166.
[3] "The Manufacture of Oxygen-Free High Conductivity Copper," by Edwin F. Cone, METALS AND ALLOYS, Vol. 8, Feb. 1937.
[4] "Softening of Copper." *Proc.* Am. Soc. Testing Material, 1925, page 25 (II.) Fig. 5.
[5] "Experiments in Wire-Drawing," Inst. Metals, No. 637.

Polishing a sheet of Enduro stainless steel. (Courtesy: Republic Steel Corp.)

Carbide Precipitation and Pitting Corrosion

"18 and 8," notwithstanding its many excellent qualities of strength and toughness together with high general corrosion resistance, nevertheless suffers from two defects which, under certain conditions of service, may seriously affect its usefulness. These are carbide precipitation, and pitting corrosion.

When first introduced by Krupp the austenitic chromium-nickel steels were claimed to be "fool proof" and entirely free from the peculiarities and objectionable qualities of the straight-chromium steels. It was heralded loudly that they were permanently austenitic, without critical temperature, and therefore, there could be no structural alteration, no matter to what temperature heated, nor how long held. There was, of course, a considerable measure of truth in all this. The crystalline grains that are formed, and the whole of the structure of the fully annealed material, may, and in most cases, will remain essentially austenitic after heating to any temperature at which the steel could reasonably be used. But this is not the whole story. When these austenitic steels are heated in the range 800 to 1500 deg. F., even for a very short interval, they undergo a structural change which, although small, may have a

and Related Stainless Steels—III

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very pronounced effect on the resistance of the metal to chemical attack. This change, now well known, involves the precipitation of carbon in the form of carbides as fine particles along the boundaries of the austenite grains. The precipitation takes very rapidly at certain temperatures, so that a heating of only a few minutes will suffice to produce a most profound effect on the corrosion resistance of the metal where such precipitation has occurred.

That carbon, or carbides, should be precipitated from austenite may appear somewhat as a paradox, particularly as there has been so wide acceptance of the idea that austenite is unique in its ability to dissolve carbon and carbides. But experiment has shown that the solubility of carbon in iron-chromium-nickel austenite is a function of the temperature, and is very low (roughly about 0.02 per cent) below the range 1550 to 1600 deg. F. Such steel when cooled rapidly from a high temperature is in a state of metastable equilibrium and can be compared to any other undercooled supersaturated solution. Precipitation of carbides will, therefore, take place, time permitting, with this range as an upper limit down to temperatures where the sluggishness of the austenite and the rigidity of the metal prohibit further change—about 800 to 900 deg. F.

The size in which the carbide particles are found determines the injury they may do. Large isolated carbide particles are not especially harmful, and act like any other inclusion; but closely spaced small particles, such as become discernible in the microscope at about 1500 diameters, and located in the grain boundaries, are very harmful.

Effects of Carbide Precipitation

In precipitation carbon is usually assumed to appropriate chromium from solid solution for the formation of chromium-rich carbides, with resulting highly localized depletion of chromium in the intergranular spaces. The result is greatly reduced corrosion resistance in those regions where precipitation has taken place. This is the generally accepted hypothesis. However, an alternative has been proposed which suggests that the carbides are primarily iron carbides, and the decreased corrosion resistance at the grain boundaries, where the carbides separate, is then ascribed to the setting up of local stresses. While the greater corrodibility of metal under stress is well known, it seems improbable that any condition of stress alone can explain the severity of the attack that may occur in the grain boundaries. Further, it is difficult to understand why iron carbide should have greater ability to set up stresses than chromium carbide.

Whether the carbides are chromium or iron, the effects of their precipitation are definite and various. The most serious is the loss in corrosion resistance along the grain interfaces, which, in certain media, may be so severe that the metal is reduced to a group of mechanically interlocked crystals and rendered utterly useless. If the environment is such as will not produce intergranular corrosion the effect on physical properties is a small, but distinct, increase in tensile strength, yield point, and hardness, with decrease in ductility and impact strength. By themselves such modifications are not sufficient to impair seriously the usefulness of the steel; but if heating in the danger range of temperature is continued over a very long period, as in high temperature service, the general effect is increased, and may reach a maximum of 20 per cent increase in tensile strength accompanied by a 40 per cent reduction in ductility.

The effects of carbide precipitation will become evident whenever the steel is heated in the range 800 to 1500 deg. F., and as this can occur in fabrication by welding, or in actual service, the usefulness of the steel, unless otherwise safeguarded, will be seriously impaired thereby. Not only will precipitation take place by heating in this range, but also during slow cooling from higher temperatures. Therefore, rapid cooling is essential, and the importance of this cannot be too strongly emphasized. For instance, the time taken to pass through the precipitating temperature range, for a 1-in. round bar heated to 2000 deg. F. and allowed to cool freely in air, will not be sufficiently short to avoid the formation of some carbides. The precipitation of carbides during even moderately slow cooling prohibits the use of forged or rolled material without subsequent heat treatment. Thus the higher physicals of bars that have been rolled at moderate temperatures, although interesting to the engineer, should be regarded with suspicion, since such steel will almost invariably show precipitated carbides along the grain boundaries. Working at moderate temperatures, which may be considered "cold" for these austenitic steels, is dangerous, and not to be confused

Ammonia oxidation towers of the E. I. du Pont de Nemours & Co. Repauno plant, Gibbstown, N. J. They are made of plates of 16 to 18 per cent chromium steel, varying in thickness from 1/4 to 3/8 in. About 115 tons of Enduro plates were used. (Courtesy: Republic Steel Corp.)

with cold working at *room* temperature, after which reheating will produce carbide precipitation of an entirely different character.

Overcoming Carbide Precipitation

Since the effects of carbide precipitation are so objectionable and in some cases disastrous, much effort and thought has been expended in finding a means of overcoming it. Some of the methods for doing this may be considered accordingly. They are as follows:

(1) Since carbon is the principal offender, eliminate it from the steel. This is more easily said than done. To produce carbonless "18 and 8," or even with maximum 0.02 per cent C, is not commercially feasible at the present time. The next consideration is to maintain carbon as low as possible. This is now being done, and specifications usually call for a maximum of 0.07 per cent C for steel for severe applications. An English producer claims to supply material of 0.03 per cent maximum C, but it is questionable whether material of even 0.02 per cent C is entirely free from carbide precipitation under very adverse conditions.

As an alternative, it has been claimed that by increase in alloy content, as by raising chromium and nickel and maintaining a certain minimum, carbide precipitation might be avoided. This is now known definitely not to be the case. Steels with content as high as 25 per cent Cr with 12-15 per cent Ni show carbide precipitation in a strikingly analogous manner.

For general applications, where only mildly corrosive conditions are encountered, as for kitchen and cafeteria equipment, architectural decorative work, automobile trimmings, dairy and food processing machinery, etc., the effects of carbide precipitation will not be sufficiently severe, even with carbon as high as 0.10-0.12 per cent, to require any preventive treatment. During the fabricating operation on the thin sheets commonly used for such applications the metal will seldom be maintained in the danger range of temperature for a sufficient time to cause injury.

But for equipment exposed to severely corroding media, as in the chemical manufacturing and process industries, and particularly where the metal will be exposed to the danger range of temperature for long periods of time, even the low content of 0.07 per cent C may produce sufficient precipitation to cause embrittlement or corrosion, and some method of avoiding this must be employed.

(2) Retreatment of the steel after fabrication, or whatever operation has caused the carbides to be precipitated, obviously, will restore the solid solution, and is all that is necessary. Sometimes this will be possible, but more often not, because of the shape or size of the piece *e.g.* there may be no furnace large enough, nor able to maintain a sufficiently high temperature. Or, if such furnace be available it would be difficult, if not impossible, to cool the piece at sufficiently rapid or uniform rate to avoid the precipitation of at least some carbides. Further, treatment at a high temperature would be ruinous to the polished surfaces of any equipment. In addition, such treatment will not solve the difficulty of equipment or machinery which in service must be maintained in the danger range of temperature, as is frequently the case. Hence, some other method must be considered.

(3) If carbon cannot be held to a sufficiently low limit, or if heat treatment after the occurrence of carbide precipitation is not possible, some method must be devised in which precipitation of carbides is allowed to take place,

but in such form that either no, or a minimum of, sensitization to corrosive attack occurs. This can be done as follows:

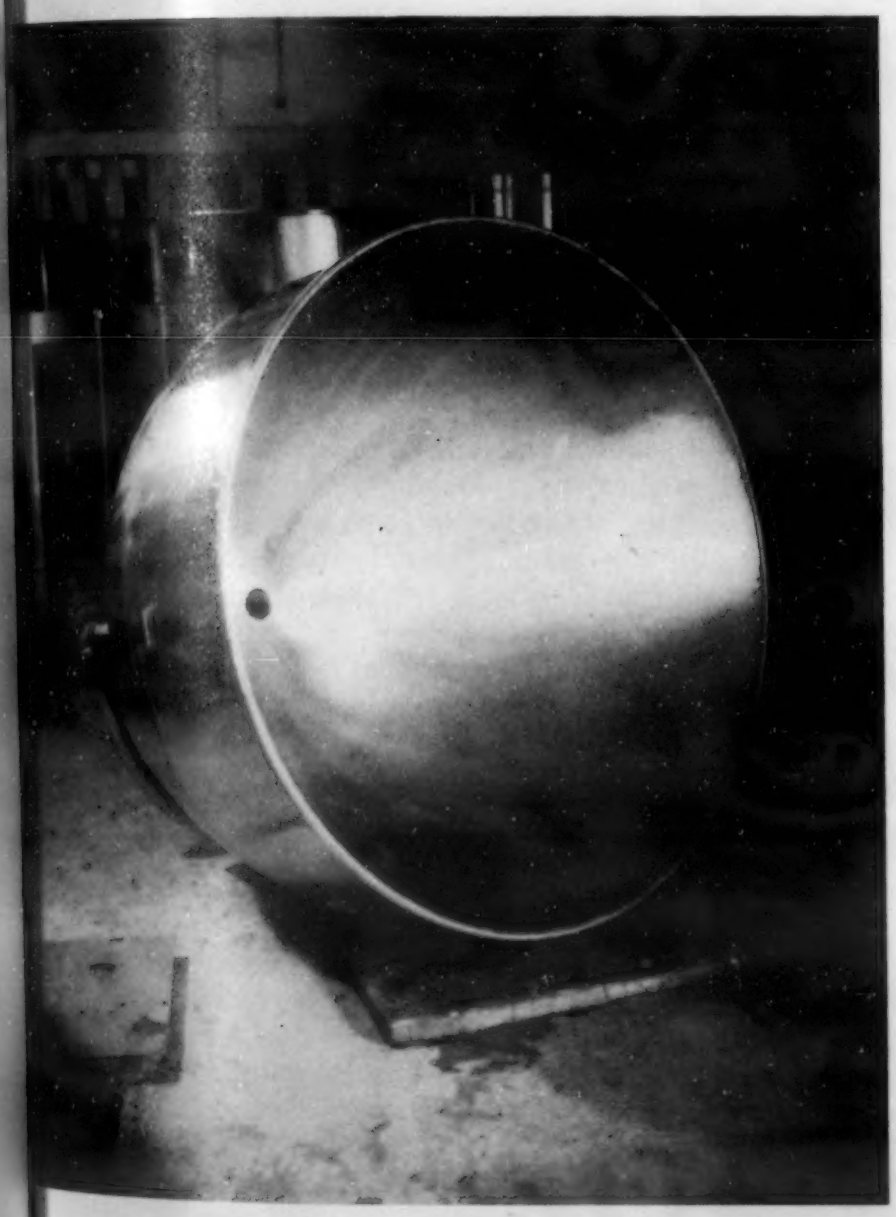
Since precipitation preferentially takes place in areas of molecular irregularity, *i.e.*, the crystalline interfaces, it has been suggested that by increasing the number of such surfaces, as by slip along crystalline planes through severe cold working, and following by heating in the precipitation range, a wider and more general distribution of carbides might be induced which would be less harmful. This has been found to be the case, and such "cold worked equilibration" is a possible method of reducing the highly localized sensitization along grain boundaries.

Other Methods

A second method of "tolerating" carbide precipitation is based on the fact that, as precipitation of carbides in ferrite takes place more freely and in a different manner than in austenite, initial production ferrite-forming elements (molybdenum, vanadium, silicon, aluminum, *etc.*) or by sufficiently varying the chromium content, would tend to distribute the precipitation of carbides to regions other than the grain boundaries. To render this method effective the steel must be produced with a relatively large proportion of ferrite phase, and this has actually been accomplished by use of high percentages of silicon; but so many of the valuable properties of "18 and 8" depend on the homogeneity of its austenitic structure that this method has not been generally adopted. Incidentally the hot working qualities of the 2-phase alloy leave much to be desired.

A third method—and that in currently widest use—is to introduce some other element that will modify the composition of the precipitated carbide so as to prohibit, or at least, greatly reduce the localized sensitization to attack, but which will be without deleterious effect on the metal as a whole. The best of such additions are carbide forming elements and, to be effective, elements for which carbon has greater affinity than it has for chromium. Such elements are available, the most important being columbium, titanium, molybdenum, and tungsten. Besides the addition of the element, a heat treatment of the metal is advisable to ensure that the added element can function to its maximum capacity in decoying the carbon from its previously preferred combination.

Stainless steel kettles built by Metal Crafts, Inc., East Orange, N. J., for Cranberry Canners, Inc., South Hanson, Mass. (Courtesy: Republic Steel Corp.)



Stabilization

The work of Bain, Aborn and Rutherford, and that of Becket and Franks, has shown that titanium and columbium are very useful elements for this purpose, as both have high affinity for carbon and form stable carbides. Titanium is more abundantly available than columbium and is lower in cost, but columbium has advantages that appear to compensate for this. Experiments have demonstrated that with sufficient titanium or columbium and necessary maintenance at a temperature of about 1550 to 1650 deg. F., all of the carbon, with the exception of a trace that remains in solution, will be precipitated as titanium carbide or columbium carbide. The heat treatment of steel with added carbide-forming element at the temperature noted has been called "stabilization," because the metal is stabilized against any further change (such as carbide precipitation) at a lower temperature.

For stabilization to be successful a sufficient percentage of the stabilizing element must be available for combination with the excess carbon above that permanently remaining in solution. Experiment has shown, and this is confirmed by theory, that for low carbon and mild service conditions, a titanium content of four to six times the carbon, or a columbium content of seven to eight times the carbon, is sufficient for the purpose. For higher carbon and severe service conditions, the added percentage of either element must be increased. To make stabilization complete heat treatment should follow, and to make

Railing, trim, etc., on front and rear stairways of F. W. Woolworth Co. store, Germantown, Philadelphia. Fabricated from Enduro sheets and bars. (Courtesy: Republic Steel Corp.)

this as effective as possible sufficient time should be permitted for the completion of the reactions involved. This will be inconveniently long at temperatures under 1550 to 1600 deg. F. Above this range carbides generally remain in solution. Hence, the stabilization treatment is confined to a narrow range of temperature at about 1600 deg. F., at which maintenance for some 3 or 4 hrs. followed by air cooling will be sufficient for practical purposes. In welds, or other cases where stabilization treatment after fabrication cannot be applied, the columbium content should be increased to eight times the carbon for mild conditions, or to eleven times the carbon for severe service conditions, and such ratios have been found very effective in producing immunity to intergranular corrosion in the absence of the stabilizing heat treatment.

Titanium is less expensive than columbium, but it oxidizes readily and difficulty is experienced in retaining the necessary content in the steel; also it volatilizes in welding operations. On this account titanium-bearing "18 and 8" is not suitable for use in welding rods. The titanium is oxidized and the resulting weld metal is not free from intergranular attack. Columbium, although originally scarce, is now available in sufficient quantities for commercial use. It has the advantage that it does not oxidize readily, and there is greater recovery in the steel making; thus, its higher initial cost appears to be compensated. Welding rods, whether for base metal containing titanium or columbium, should always be made from columbium-bearing "18 and 8" and, as is good practice, the general alloy content of welding rod stock should be somewhat higher than that of the base metal to be welded.

Where columbium is used in considerable percentage it is advisable to increase the manganese content from about 0.50 per cent to between 1.0 and 2.0 per cent to improve hot working qualities. This increase in manganese is reported to be without injurious effect on either the physical properties or the corrosion resistance.

Because the chief difference between annealed and stabilized "18 and 8" is the presence of some small inert carbide particles dispersed at random through the metal, there will be little change in mechanical

or physical properties other than slightly increased tensile strength and lessened ductility. In respect to corrosion, there appears to be some slight improvement in the resistance of the stabilized "18 and 8" against certain media. Here, columbium has the advantage, since its use in no instance appears to diminish corrosion resistance, while titanium slightly reduces resistance to certain chemicals.

The important difference between stabilized and normal "18 and 8" rests on the ability of the former to withstand heating for indefinite periods at temperatures under 1600 deg. F. without becoming embrittled or susceptible to destructive corrosive attack. Therefore, its importance is felt in those applications where the metal, either in fabrication, or in actual service, is exposed to this temperature range for a longer or shorter time. A further advantage of stabilized "18 and 8" is that cooling may proceed slowly and thus avoid the setting up of stresses which, Hodge and Miller have shown, may be sufficient in certain corrosive media to cause rapid failure by cracking. For relief of stresses temperatures as high as 1600 deg. F. may be necessary, and stabilized "18 and 8" may therefore be slowly cooled, or annealed, from this temperature without producing undesirable results as in normal "18 and 8."

Pitting Corrosion

The second of the defects from which "18 and 8" suffers is pitting corrosion. While the general resistance to attack of "18 and 8" is high, and perhaps exceeds that of any other metal or alloy outside of the noble metal group, its susceptibility to this one type of corrosion is serious, and especially so because thus far all efforts to overcome it seem to have been unsuccessful. Pitting is sometimes called "worm-hole" corrosion because of the appearance of the metal, which is without general corrosion, yet is attacked sharply in localized areas, so that it appears as if attacked by "borers" or termites of some sort. The attack may be so severe and localized that the metal will be penetrated in one or more places in a short time, although general corrosion is entirely absent.

This type of corrosion occurs when "18 and 8" is exposed to dilute solutions containing halogen salts such as brines, sea-water, dilute acid solutions, cleaning solutions, and the like. The attack may occur where foreign matter is present on the surface, and will also occur frequently where the surface is supposedly clean and free from all contamination.

Much effort has been expended in investigations to ascertain the cause of this type of attack and thereby, if possible, to develop a remedy. Theories have been advanced that are sufficiently plausible in explaining why pitting should occur where foreign matter is present, and why it should continue once it has commenced but, so far, no satisfactory reason has been presented as to why, on supposedly clean metal, it should commence at all, or at one place in preference to some other.

Where foreign matter is present contact corrosion is set up and attack proceeds rapidly in the presence of suitable media, but where the metal is clean the cause of attack is more difficult to explain. Microscopically visible inclusions and carbides appear to be innocent. Nevertheless some metallurgical peculiarities must exist which affect the state of the surface, and thus invite attack, but thus far efforts to identify these peculiarities have been unsuccessful. Pitting, having once started, proceeds rapidly, so that penetration follows in a short time and the metal becomes useless for practical purposes. Oxygen deprivation in the pit itself seems to be a logical explanation for the continuance of the attack, and electrolytic action between the products of corrosion and the surrounding surface may also share in this. But the reason for the starting of the attack is still unexplained.

The addition of other elements to the "18 and 8" combination has been found helpful, but not completely successful. Molybdenum (of which more later), is the most useful. There are many reports of its effect in diminishing pitting attack or, what amounts to the same thing, in delaying the time of commencement of the attack. Wulff and Uhlig have found, rather curiously, that molybdenum, while effective against saline solutions and chloride brines is not so effective against solutions containing bromine salts, which attack both normal "18 and 8" and that with molybdenum added.

The effects of other alloying elements, with the exception of silver, have not been studied sufficiently to justify conclusions. The addition of silver, for which a patent has recently been granted to Kaye, Williams and Wulff (U. S. Patent No. 2,156,914), is claimed to produce a film of silver chloride when the metal is exposed to chloride solutions. The percentage of silver required is fractional, and the film, which is practically insoluble and self healing, is claimed to protect the metal underneath and greatly diminish the attack.

(Since the manuscript of this article was completed, an announcement has been made giving further results of investigations at Massachusetts Institute of Technology by Uhlig, Wulff, Keye, and Williams, and sponsored by Chemical Foundation. They report that the source of pitting corrosion has been found in minute points, cracks, and other imperfections in the surface of the metal. The remedy apparently consists in producing a self-healing surface film by various means, such as plating with silver or other metals, and by a thermal treatment. Patents disclosing the details of the procedure, which has not yet reached commercial practice, have been granted the investigators.) (*To be Concluded*)

EDITORIAL *(Continued from page A19)*

line, or it may not, according to chance.

Föppl[7] points out that in ordinary rotating beam fatigue testing, the operator pays no attention to whether the fracture was at the minimum section, or whether it occurs away from it, perhaps at a location corresponding to only 70 per cent of the load at the minimum section. The operator plots the point on the basis of the midsection load instead of on that at the load at the location of fracture. On the basis of trying to find out what par is for the material, this may be justifiable, since the midsection stood its calculated surface stress without fracture, but the practice tends to cover up the real scatter.

In endurance tests where the points were so plotted, but those for specimens breaking away from the midsection were designated by a different symbol[8] fully half of the fractures are indicated as not occurring at the most highly stressed portion.

In the testing of a large specimen, with a relatively great volume stressed to the maximum, the weak spots get in their work and make it impossible to cover up. Thus, tests on large specimens tend to give the lower limit of the scatter band that small-specimen tests would show if thousands and thousands were tested.

If we want to find the maximum potentialities of a material in fatigue with the smallest amount of effort, chance works with us when we use the usual rotating beam specimen, but if we wish to evaluate the engineering behavior in fatigue of a given lot of material, we need to know the lower boundary of the scatter band, not the upper limit, and there chance tends to obscure rather than to reveal what we strive to show, by our common methods of testing.

That many materials, adequately tested, give S-N scatter bands rather than a nice line, and that the stressed volume of a specimen affects the position of the upper branch of the S-N curve, as Horger and Maulbetsch so clearly show, complicate the problem of studying "damage lines."

The so-called "size effect" in fatigue may be a purely statistical matter, with nothing peculiar about it, unless it is peculiar that we tend to close our eyes to what causes it, and to do wishful thinking in the assumption that the par value of endurance limit on a set of tiny specimens is necessarily attainable in practice.—H. W. G.

References

[1] Matthaes, K. "Fatigue Strength of Airplane and Engine Materials." Tech. Memo. No. 743, Apr. 1934, Natl. Advisory Comm. for Aeronautics, from *Z. für Flugtechnik u. Motorluftschiffart.*

[2] Peterson, R. E., and A. M. Wahl. "Two-and Three-Dimensional Cases of Stress Concentration, and Comparison with Fatigue Tests." *Trans. Soc. Mech. Engrs.* Vol. 58, 1936, p. A15-A22.

[3] Chapman, E. "Maximum Stress, Its Influence on Cost and Service Life of a Structure." *J. Am. Welding Soc.*, Vol. 10, Sept. 1931, p. 19-22.

[4] Irwin, P. L. "Fatigue of Metals by Direct Stress." *Proc. Am. Soc. Testing Materials*, Vol. 25, pt. 2, 1925, p. 53-63.

[5] France, R. D. "Endurance Testing of Steel; Comparison of Results Obtained with Rotating Beam vs. Axially Loaded Specimens." *Proc. Am. Soc. Testing Materials*, Vol. 31, pt. 2, 1931, p. 76-191.

[6] Horger, O. J. and J. L. Maulbetsch. "Increasing the Fatigue Strength of Press-Fitted Axle Assemblies by Surface Rolling." *Trans. Am. Soc. Mech. Engrs.*, Vol. 58, 1936, p. A91-A98.

[7] Föppl, O. "The Practical Importance of the Damping Capacity of Metals, Especially Steels." *J. Iron Steel Inst.*, Vol. 134, 1936, p. 393-455.

[8] Gillett, H. W. and E. L. Mack. "Molybdenum, Cerium and Related Alloy Steels." Reinhold Publishing Corp., New York, 1925.

A FEW CHUCKLES

Steel Industry Gone To The Dogs?

To the Editor: While browsing through some reports the other day, I came upon the enclosed picture. Being a "doodler" myself, I was interested in the structure itself.

Imagine my surprise when I turned the photograph upside down and saw a Scotty dog, with a blanket on in the bottom left hand corner!

Has the steel industry gone to the dogs?

(Miss) LaVerne M. Flinner

2219 Broadway Ave.,
Pittsburgh

The Sphinx—or What Have You!

To the Editor: I have been meaning to send this in to you for publication in "A Few Chuckles" for some time. The subject is a piece of Ni-Hard at 1000 X on a 5 by 7-in. plate. It was not noticed until after the print was made that a portion of it very closely resembled the Sphinx.

The photomicrograph was made by Prof. H. Vance White of the metallurgical department of the Virginia Polytechnic Institute. As this figure appeared at the extreme edge of the plate I spent over an hour vainly seeking the portion shown in order to make a better picture of it to send to you. If you think that it has interest for other readers of Metals and Alloys you are at liberty to publish it.

Edwin C. Davis
Ass't. Prof. of Metallurgy

V. P. I.
Blacksburg, Va.